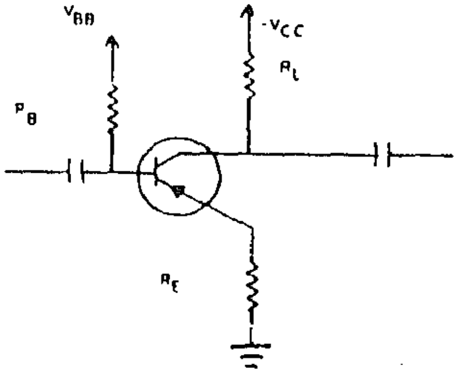
FOR

ADVANCED FIRST-TERM AVIONICS COURS

CLASS A1

C-100-2010



UNIT II

CNTT-M1704

PREPARED BY

NAVAL AIR TECHNICAL TRAINING CENTER

NAVAL AIR STATION MEMPHIS

MILLINGTON TENNESSEE

PREPARED FOR

CHIEF OF NAVAL TECHNICAL TRAINING

NOVEMBER 1984

FOREWORD

e of this Student's Guide is to assist you in comple
istor Theory," Unit II, of the Advanced First-Term
ourse. The proper use of this guide will increase y
in the above mentioned areas, while building a basis
future training will be built.

of contents lists the page numbers for safety notice
sheets, information sheets, and references that wil
hance your abilities and skills as an aviation elect
.

SAFETY NOTICE

As a Navy electronics technician, you will be required
safe and efficient maintenance on various types of elec
equipment. Not only your life, but the lives of many o
depend on your being safety conscious at all times. It
responsibility of all Navy and Marine Corps personnel t
accidents. This can be done if everyone develops consc
safety habits and observes all precautions when perform
nance of any type. Always remember:

SAFETY CANNOT BE OVERSTRESSED!!!!!

HOW TO USE THIS STUDENT'S GUIDE

s Guide" has been prepared for you to use while you
the Advanced First-Term Avionics Course (Class A1).
s been provided for taking notes on the required
tion. Remember when you are in class, the informa-
vided by your instructor is information you will need
your Navy job.

ntains the following:

sheets, containing lesson topic outlines,
ons, and ample space for personal notetaking.

n sheets to provide information pertinent to your

arn all you can!

The schedule is as follows:

TOPIC NO.	TYPE	PERIOD	TOPIC
SECOND WEEK			
Fifth Day			
2.1	Class	67	Series Resonance
		78	
		79	
2.2	Class	80	Parallel Resonance
THIRD WEEK			
First Day			
2.2	Class	81	Parallel Resonance
2.3	Class	82	Physics Overview
		83	
		84	
2.4	Class	85	Semiconductor Physi
		86	
		87	
		88	
Second Day			
2.4	Class	89	Semiconductor Physi
2.5	Lab	90	PN Junctions (Labor
		91	
2.6	Class	92	Junction Transistor
		93	
		94	
		95	
		96	

	99	
	100	
Class	101	Biasing Arrangements
	103	
	104	
Class	105	Biasing Arrangements
	106	
	107	
Lab	108	Biasing Arrangements (Laborato
	109	
	110	
	111	
	112	
Class	113	Unit/Module Test: Criterion T Written Examination
	114	
	115	
Class	116	Decibels
	117	
Class	118	Féedback Amplifiers
	119	
	120	
Class	121	Feedback Ampilfiers
	122	
	123	
Class	124	Direct Coupled and Operationa Amplifiers
	125	
	126	

		130	
		131	
		132	
2.14	Class	133	Special Device
		134	
		135	
		136	

Third Day

2.14	Class	137	Special Device
		138	
		139	
		140	
2.15	Class	141	Vacuum-Tube Fu
		142	
2.16	Class	143	Triodes
		144	

Fourth Day

2.16	Class	145	Triodes
		146	
		147	
		148	
2.17	Class	149	Multielement
		150	
		151	
		152	

Fifth Day

	Class	153	Unit/Module Test/Writte
		154	
		155	
		156	

plete assigned homework may result in disciplinary

Sheet	Period Due
	81
	89
	89
	97
	97
	113
	121
	129
	129
	137
	145
	145
	153
	153

mathematics, algebra, and trigonometry. A formula
trigonometric tables, and a Universal Time Constant
be provided. Performance must be in accordance wit
matical principles outlined in Mathematics, Vol. I,
10069 (series), Mathematics, Vol. III, NAVPERS 1007
Basic Electronics, Vol. I, NAVPERS 10087 (series),
Electricity, NAVPERS 10086 (series). Performance w
measured by a written multiple-choice examination.

2.0 ANALYZE the internal structure and operation of sem
junctions by tracing majority and minority current
a given semiconductor device, in accordance with qu
mechanical principles outlined in Basic Electronics
NAVPERS 10087 (series) and Aviation Electronics 3 &
NAVEDTRA 10317 (series). Performance will be measu
written multiple-choice examintion.

3.0 Mathematically ANALYZE the operation of given basic
conductor circuits by solving problems in terms of
current, reactance, and frequency. A formula sheet
provided. Responses must be in accordance with Bas
Electronics, Vol. I, NAVPERS 10087 (series), and pe
will be measured by a written multiple-choice exami

4.0 ANALYZE the internal structure and operation of vac
circuits by identifying elements and their function
SOLVING problems in terms of voltage, current, resi
biasing. Responses must be in accordance with info
outlined in Basic Electronics, Vol. I, NAVPERS 1008
Performance will be measured by a written multiple
examination. A formula sheet will be provided.

ENABLING OBJECTIVES

1.1 SOLVE problems involving addition, subtraction, mul
and division of radicals and exponents, using the l
exponents. Response must be in accordance with Mat
Vol. I, NAVPERS 10069 (series). Performance will b
by a written multiple-choice examination.

1.2 SOLVE problems involving the addition, subtraction,
cation, division, evaluation, and simplification of
expressions. Response must be in accordance with M
Vol. I, NAVPERS 10069 (series). Performance will b

SOLVE for total capacitance, RC time, curent, and volta values of a simple RC switching circuit. Response must accordance with Basic Electricity, NAVPERS 10086 (serie Performance will be measured by a written multiple-choi examination. A formula sheet and a Universal Time Cons Chart will be provided.

SOLVE for total inductance, L/R time, current, and volt values of a simple L/R switching circuit. Response mus accordance with Basic Electricity, NAVPES 10086 (series Performance will be measured by a written multiple-choi examination. A formula sheet and a Universal Time Cons Chart will be provided.

SOLVE for unknown current, voltage, and resistance valu electronic circuits containing source characteristics a voltage dividers. Response must be in accordance with Electricity, NAVPERS 10086 (series). Performance will measured by a written multiple-choice examination. A f sheet will be provided.

SOLVE for unknown values of current, voltage, reactance power in series and parallel a-c circuits. Response mu in accordance with Basic Electricity, NAVPES 10086 (ser Performance will be measured by a written multiple-choi examination. A formula sheet and trigonometric tables provided.

SOLVE for unknown values of current, voltage, reactance frequency, bandwidth, and circuit "Q", in series and pa resonant circuits. Response will be in accordance with Electronics, Vol. I, NAVPERS 10087 (series). Performan be measured by a written multiple-choice examination. A sheet and trigonometric tables will be provided.

SELECT, from a given list, correct statements concernin structure of an atom, given an element from the Periodi of Chemical Elements. Responses must be in accordance Basic Electronics, Vol. I, NAVPERS 10087 (series). Per will be measured by a written multiple-choice examinati

SELECT, from given lists, correct statements related to properties of heat, sound, cryogenics, and the electron

ETERMINE normal biasing polarities of semiconductor jun
y ANALYZING majority and minority current through a giv
emiconductor circuit. Responses must be in accordance
uantum principles outlined in Basic Electronics, Vol. I
AVPERS 10087 (series). Performance will be measured by
ritten multiple-choice examination.

ETERMINE biasing arrangements of semiconductor circuits
OLVING problems in terms of voltage, current, reactance
requency. Responses must be in accordance with Basic
lectronics, Vol. I, NAVPERS 10087 (series). Performanc
e measured by a written multiple-choice examination. A
ormula sheet will be provided.

ETERMINE capabilities, electrical characteristics, adva
nd disadvantages of given semiconductor circuits by SOL
roblems in terms of voltage, current, reactance, and fr
y. Responses must be in accordance with Basic Electron
ol. I, NAVPERS 10087 (series). A formula sheet will be
rovided.

OMPUTE decimal gain and loss in terms of the voltage an
f a given semiconductor amplifier circuit. Responses m
n accordance with Basic Electronics, Vol. I, NAVPERS 10
series). A formula sheet will be provided. Performanc
e measured by a multiple-choice examination.

UILD basic semiconductor amplifier circuits (under supe
ision). MEASURE values and RECORD measurements, calcul
nd evaluations on a job sheet, given necessary test equ
nd an RCA 6F16 transistor trainer. Accuracy will be me
n accordance with information contained in Basic Electr
ol. I, NAVPERS 10087 (series).

ELECT, from given lists, the names and functions of the
lements contained within a vacuum-tube. Responses must
ccordance with information outlined in Basic Electronic
ol. I, NAVPERS 10087 (series). Performance will be mea
y a written multiple-choice examination.

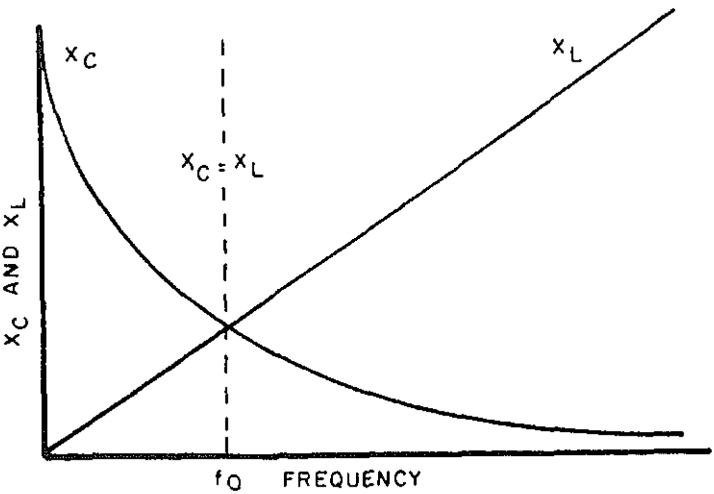
OLVE problems in terms of voltage, current, resistance
iasing, using vacuum-tube formulas and tube constants.
esponses must be in accordance with information outline

IAL

OUTLINE:

eral Information

onant Frequency



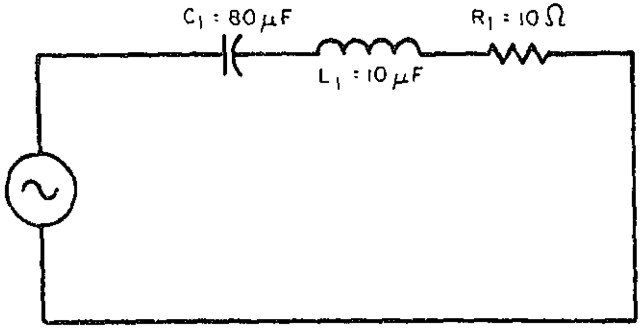


Figure 2. Series Resonant Circuit

III. Resonant Series Circuit Analysis

RLC Circuit Analysis

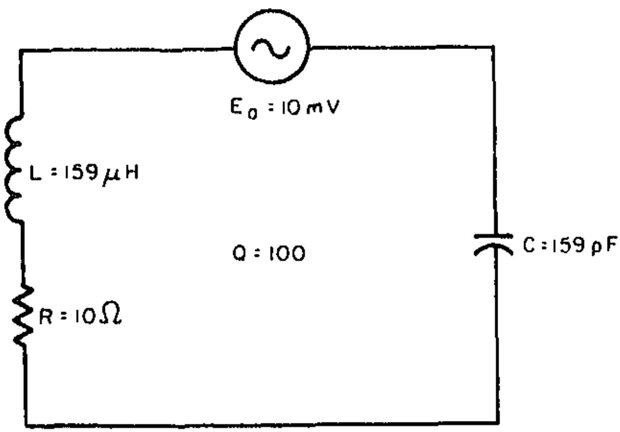
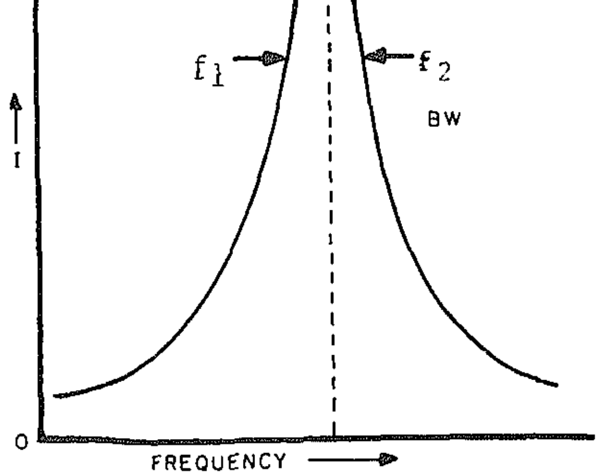
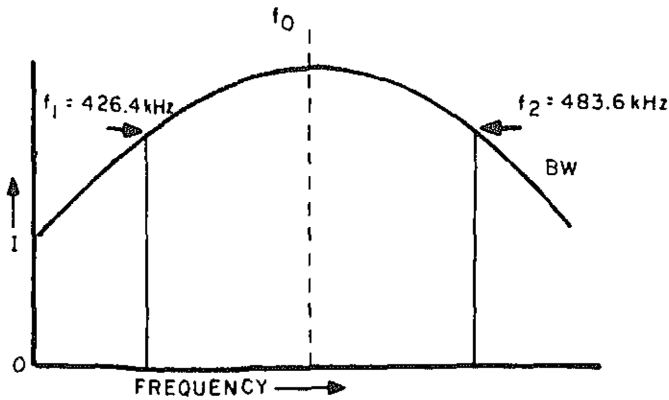


Figure 3. Series RLC circuit



(A) HIGH Q CURRENT CURVE



(B) LOW Q CURRENT DRIVE

Figure 4. Bandwidth curves

ectronics, Vol. 1, NAVPERS 10087-C, Chapter 10,
)3 to 209.

. Shrader, Electronic Communication, Fourth Edition,
ill, Inc., 1980, Chapter 8, pages 123-131.

UTLINE:

l Parallel Resonance

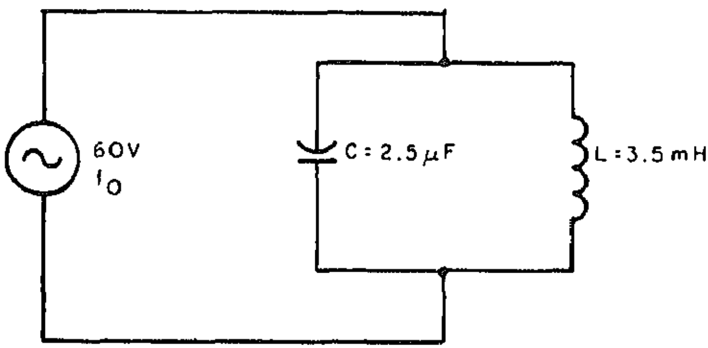


Figure 1. Parallel LC Circuit at Resonance

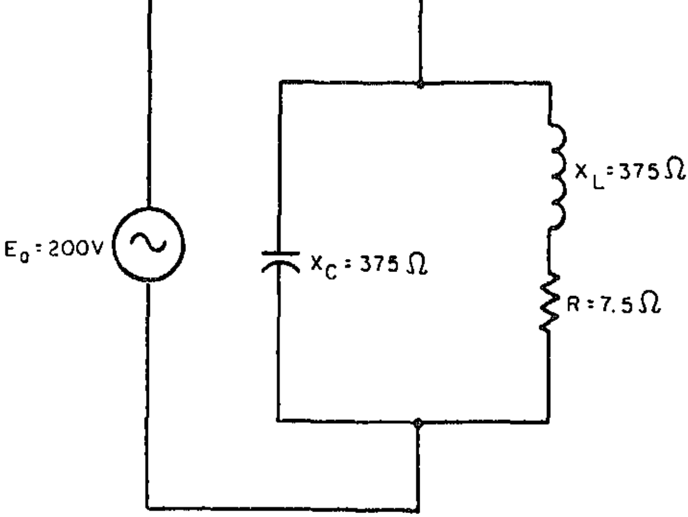
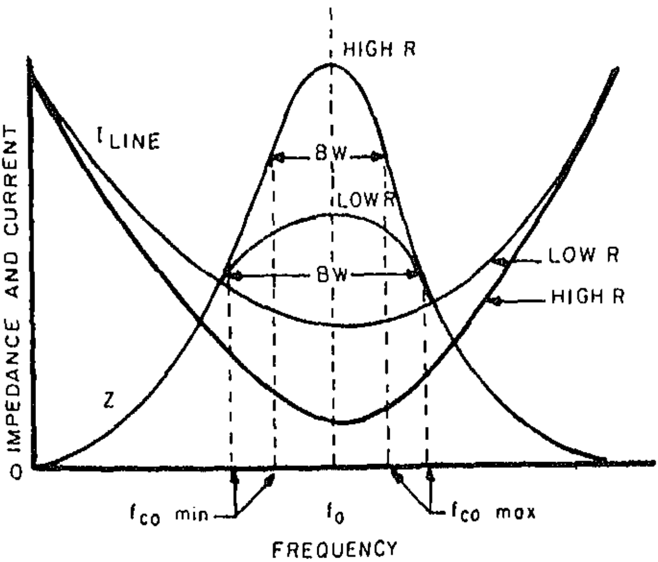


Figure 2. Parallel Resonant Circuit with Parallel Resistance.

III. Bandwidth Considerations



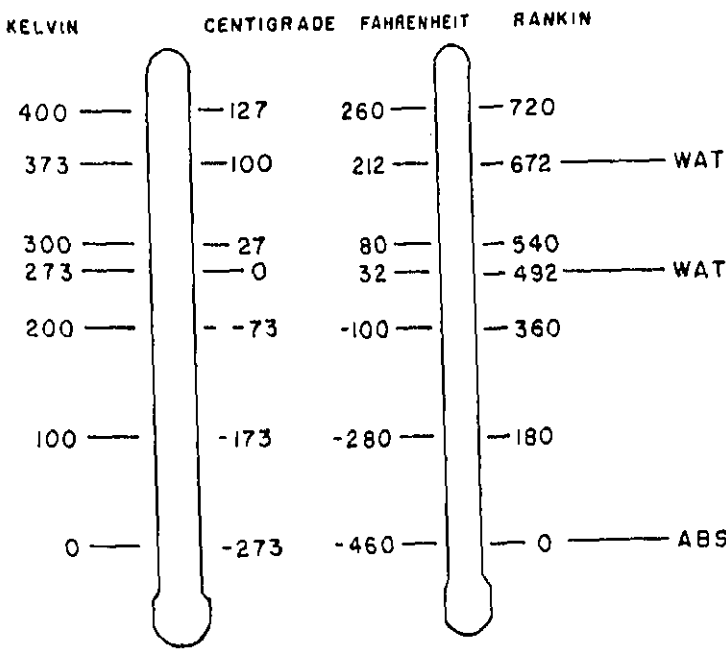
Metcalf, Trinklein, and Lefler. Modern Physics. Holt, Rinehart, and Winston, 1968. Chapters 1, 7, 27.

OUTLINE

tter

III. The Relationship Between Matter and Energy

IV. Cryogenics



LEMENT	TEMPERATURE AT WHICH ELEMENT BECOMES SUPERCONDUCTIVE
iobium	8.0 K.
ead	7.2 K.
antalum	4.4 K.
ercury	4.2
horium	1.4
luminum	1.2
inc	0.91
itanium	0.4

Figure 2. Superconductivity Chart

nd

VELOCITY OF SOUND	MEDIUM
1,087 FT./SEC	IN AIR AT 32° F
4,794 FT./SEC	IN WATER
16,500 FT./SEC	IN STEEL

Figure 3. Velocity of Sound in Various Mediums

VI. Light

VII. Heat

Units of heat measurement

Methods of heat transference

ION

tanding of basic physical and chemical properties is
to the study of electronics. Even the more complex
c devices can be reduced to a study of electron beha
or gases. To follow explanations for semiconductor
for example, the technician must have a knowledge of
d together to make a crystal.

: Dull, Metcalf, and Williams. Modern Physics. Ne
York, N.Y.: Holt, Rinehart, and Winston, Inc., 1
Chapter 6, pages 133-151.

ON

DUCTION TO THE PERIODIC CHART OF THE ATOMS

any of the early scientists saw that the periodicity
hythm to atomic behavior could be shown graphically.
oday, the physical significance of such a rhythm is
he "Periodic Chart of the Atoms" is the graphic port
f this significance. As late as 1870, there were on
lements known. At this time, some system of catalog
he atoms was attempted. First, they cataloged by at
eights. The weights of the elements were soon found
ariable, depending on the number of isotopes. A lit
ater, it was found that the atomic number (number of
ons in the nucleus) was more stable. Even though th
umber of elements known did not complete the chart,
ave rise to speculation that the missing atomic numb
ay be unknown elements. By 1900, the inert gases we
iscovered and the chart began to fill out. In 1913,
sotopes were discovered. They also fit into the rhy
he chart. An isotope is a basic element with a diff
tomic weight. It was simply a matter of listing all
sotopes of an element under the same position on the
eriodic Chart; they all have the same atomic number
ifferent atomic weights. Today, we have the Periodi
hart in its entirety from Atomic Number 1 to Atomic
03. Refer to figure 1, Periodic Chart; there are no
etween the known first and last elements, but this d
ot mean to say that there are no more beyond 103. E
he men who built our modern chart left space for thr

of outermost planets or valence ...
is the number of shells. The Periodic System i
complete with all stable atoms discovered and a
numbers and position. The outer planet system
completed by the discovery of the six inert gas
atmosphere, Group VIII atoms. Each row (or dou
ends with one of these inert atoms.

II. PERIODIC CHART DATA

A. Atomic symbol

1. All atoms have symbols. The "Periodic Char atomic symbols; examples are hydrogen, H; oxygen, O; and uranium, U.

2. All elements exist in one of three physical forms are solids, liquids, or gases. The each element's symbol by a color that repre form in which it is found to exist in natu not shown in figure 1).

3. Black symbols represent solids. Some examp solids are carbon, silicon, iron, and gold

4. Blue symbols represent liquids. There ae known liquids; bromine, mercury, gallium,

5. Orange symbols represent gases. Some examp hydrogen, oxygen, argon, krypton, and zenon

B. Atomic number

1. The atomic number appears on the chart as black number. Refer to figure 1, "Periodi

2. The atomic number represents the number of the nucleus of the atom. Since atoms are neutral, they must contain equal numbers o electrons. Thus, the atomic number also e number of electrons in an atom. The atomi the "key" to the periodic chart. Refer to "Distribution of Electrons"; starting with which has one proton and one electron, eac element increases by one proton and one el increase by one takes place ...

26Fe--Iron, Z = 26

54Xe--Xenon, Z = 54

s

ı a proton is added to the nucleus and an electron ıdded to the shells, a new atom is formed. If a ːron enters the nucleus a new atom is not formed. ıough dead weight is added, such an atom behaves ıically as before. These atoms with the same number ɔrotons but different numbers of neutrons ae called <u>:opes</u> of the same element.

example of an element with three isotopes in ːogen (H). Shown in figure 2 are the three ːopes of hydrogen.

basic hydrogen atom, protium, has one proton and no ːrons.

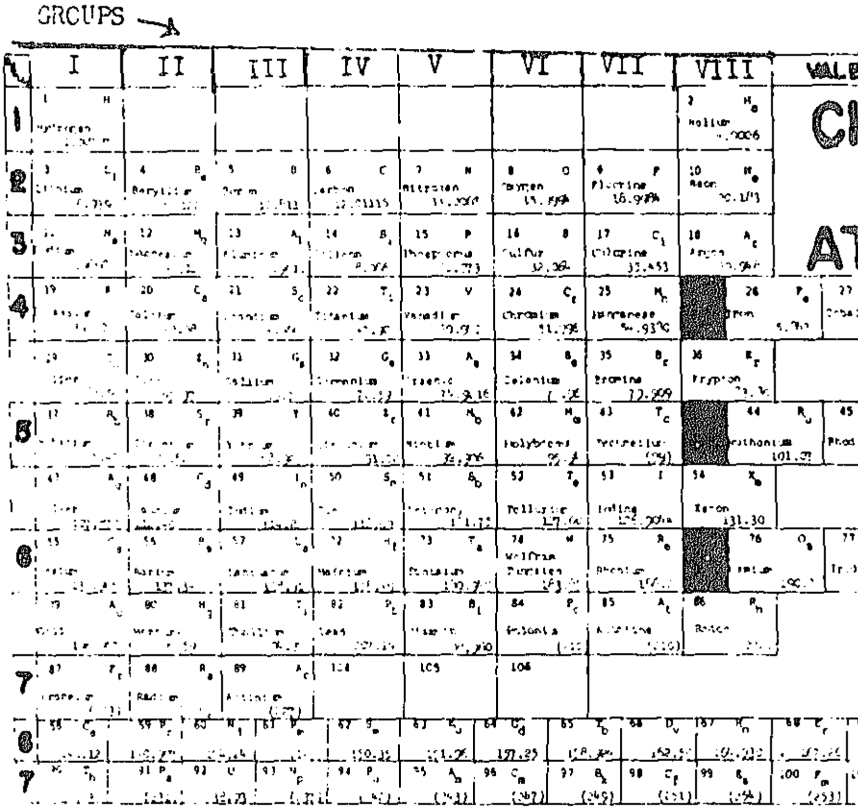

GROUPS
I
II
III
IV
V
VI
VII
VIII
Hydrogen
Helium
Beryllium
Carbon
Nitrogen
Oxygen
Fluorine
Neon
Sulfur
Chlorine
Argon
Titanium
Vanadium
Chromium
Manganese
Iron
Gallium
Germanium
Arsenic
Selenium
Bromine
Krypton
Molybdenum
Technetium
Ruthenium
Indium
Tellurium
Iodine
Xenon
Barium
Lanthanum
Hafnium
Tantalum
Wolfram
Rhenium
Lead
Polonium
Astatine
Radon
Radium
Actinium

Figure 1

ELEMENT	K	L	M	N	O
ydrogen	1				
elium	2				
ithium	2	1			
eryllium	2	2			
oron	2	3			
arbon	2	4			
itrogen	2	5			
xygen	2	6			
luorine	2	7			
eon	2	8			
odium	2	8	1		
agnesium	2	8	2		
luminum	2	8	3		
ilicon	2	8	4		
hosphorus	2	8	5		
ulphur	2	8	6		
hlorine	2	8	7		
rgon	2	8	8		
otassium	2	8	8	1	
alcium	2	8	8	2	
candium	2	8	9	2	
itanium	2	8	10	2	
anadium	2	8	11	2	
hromium	2	8	12	2	
anganese	2	8	13	2	
ron	2	8	14	2	
obalt	2	8	15	2	
ickel	2	8	16	2	
opper	2	8	18	1	
inc	2	8	18	2	
allium	2	8	18	3	
ermanium	2	8	18	4	
rsenic	2	8	18	5	
elenium	2	8	16	6	
romine	2	8	18	7	
rypton	2	8	18	8	
ubidium	2	8	18	8	1
trontium	2	8	18	8	2
ttrium	2	8	18	9	2
irconium	2	8	18	10	2
iobium	2	8	18	11	2
olybdenum	2	8	18	12	2

ATOMIC NO.	ELEMENT	K	L	M	N	O	P
43	Technitium	2	8	18	13	2	
44	Ruthenium	2	8	18	14	2	
45	Rhodium	2	8	18	15	2	
46	Palladium	2	8	18	16	2	
47	Silver	2	8	18	18	1	
48	Cadmium	2	8	18	18	2	
49	Indium	2	8	18	18	3	
50	Tin	2	8	18	18	4	
51	Antimony	2	8	18	18	5	
52	Tellurium	2	8	18	18	6	
53	Iodine	2	8	18	18	7	
54	Xenon	2	8	18	18	8	
55	Cesium	2	8	18	18	8	1
56	Barium	2	8	18	18	8	2
57	Lanthanum	2	8	18	18	9	2
58	Cerium	2	8	18	19	9	2
59	Pra'mium	2	8	18	20	9	2
60	Neodmium	2	8	18	21	9	2
61	Promethium	2	8	18	22	9	2
62	Samarium	2	8	18	23	9	2
63	Europium	2	8	18	24	9	2
64	Gadolinium	2	8	18	25	9	2
65	Terbium	2	8	18	26	9	2
66	Dysprosium	2	8	18	27	9	2
67	Holmium	2	8	18	28	9	2
68	Erbium	2	8	18	29	9	2
69	Thulium	2	8	18	30	9	2
70	Ytterbium	2	8	18	31	9	2
71	Lutetium	2	8	18	32	9	2
72	Hafnium	2	8	18	32	10	2
73	Tantalum	2	8	18	32	11	2
74	Tungsten	2	8	18	32	12	2
75	Rhenium	2	8	18	32	13	2
76	Osmium	2	8	18	32	14	2
77	Iridium	2	8	18	32	15	2
78	Platinum	2	8	18	32	16	2
79	Gold	2	8	18	32	18	1
80	Mercury	2	8	18	32	18	2
81	Thallium	2	8	18	32	18	3
82	Lead	2	8	18	32	18	4
83	Bismuth	2	8	18	32	18	5
84	Polonium	2	8	18	32	18	6

85	Astatine	2	8	18	32	18	7	
86	Radon	2	8	18	32	18	8	
87	Francium	2	8	18	32	18	8	1
88	Radium	2	8	18	32	18	8	2
89	Actinium	2	8	18	32	18	9	2
90	Thorium	2	8	18	32	19	9	2
91	Protactinium	2	8	18	32	20	9	2
92	Uranium	2	8	18	32	21	9	2
93	Neptunium	2	8	18	32	22	9	2
94	Plutoium	2	8	18	32	23	9	2
95	Americium	2	8	18	32	24	9	2
96	Curium	2	8	18	32	25	9	2
97	Berkelium	2	8	18	32	26	9	2
98	Californium	2	8	18	32	27	9	2
99	Einsteinium	2	8	18	32	28	9	2
100	Fermium	2	8	18	32	29	9	2
101	Mendelevium	2	8	18	32	30	9	2
102	Nobelium	2	8	18	32	31	9	2
103	Lawrencium	(Unknown)						

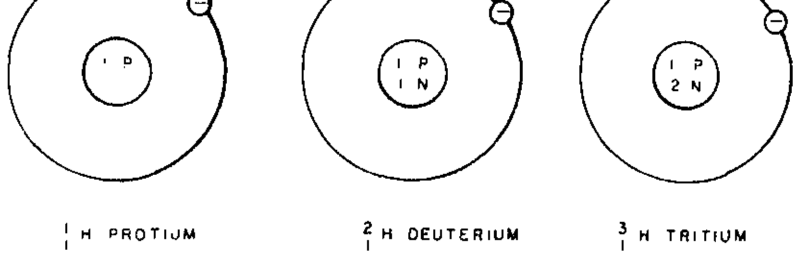


Figure 2

second hydrogen atom, deuterium, has 1 proton and eutron. The third hydrogen atom, tritium, has 1 oton and 2 neutrons. The three hydrogen isotopes , ^2_1H, and ^3_1H) given individual names to identify em. These names ae protium (^1_1H), deuterium (^2_1H), tritium (^3_1H). Almost all elements have more than isotope.

Weight

atomic weight is the weighted <u>average</u> of the otopes based on their relative abundance. The atomic ght is shown in figure 1, "Periodic Chart."

average weight of the three isotopes in hydrogen is 0797 AMU (Atomic Mass Units) (1 AMU = 1.66×10^{-24} ams). The figure for atomic weight is a relative ber and its only real importance is to the chemist.

atomic weight is not the same as the number of otons and neutrons in the nucleus. The mass number the number of protons and neutrons and is a whole ber.

on Shells

orbits in which electrons must revolve about the cleus of an atom are called electron shells, or quanta vels. The shells are labelled K, L, M, N, O, P, Q om the innermost (K) to the outermost (Q). Table I,

shell (K) and work outward. In most shell fills first, then the "L" shell, and is not an absolute law; there are some ir At this time we are not interested in the irregularities.

3. Study Table 1, "Distribution of Electrons" that none of the elements has more than tw the first shell (K). In the case of hydro only one electron and it is in the "K" she other elements, only two electrons can exi shell. To predict the maximum number of e may occupy any given shell, use the equati indicates the number of the shells). In t first shell (K), the equation states:

$$2(N^2)$$

$$2(1^2)$$

$$2(1) = 2 \text{ electrons.}$$

The "K" shell in any element cannot contain two electrons. In the second shell (L), th states:

$$2(N^2)$$

$$2(2^2)$$

$$2(4) = 8 \text{ electrons.}$$

The "L" shell in any element cannot contain electrons. All electrons do contain the max electrons except those that do not have enou available to fill the shell (Z = 1 to Z = 9. example, Germanium; the equation states: "K electrons; "L" shell, 8 electrons; "M" shell trons; and "N" shell, 32 electrons. Refer t "Distribution of Electrons." The table show germanium has 32 electrons (Atomic Number 32 are distributed "K" = 2, "L" = 8, "M" = 18, The last shell in germanium (N) only contain trons, even though the equation pr...

partially filled? An example of this is potassium, 19): notice the "K" shell = 2, "L" shell = 8, "M" = 8, "N" shell = 1. To explain why the "M" shell ot take the one electron that went to the "N" , we must delve deeper into the construction of the s.

, L, M, N, O. P, Q shells are called the <u>main</u> <u>s</u>. Each main shell after the "K" shell is made <u>subshells</u>. The number of subshells (or sub-als) that are present within a main shell is in figure 3.

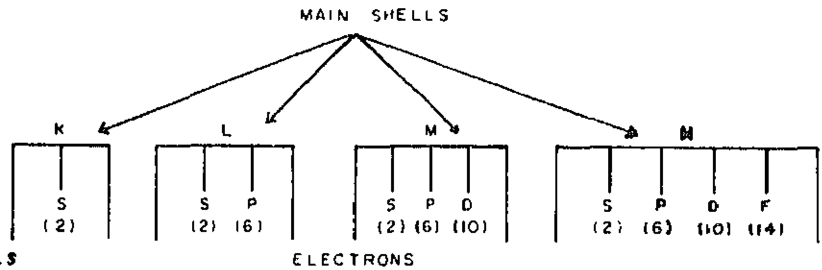


Figure 3

in figure 3, each subshell that exists within a shell as a set number of electrons. Each one of S" subshells in any main shell contains two rons. Each succeeding subshell always has four rons more than its preceding subshell. Remember, s stated earlier that a main shell will fill, in cases, before the next main shell begins. To be specific, a subshell will fill prior to the next ell out within a main shell. If a subshell in the hell cannot be filled, the electrons will move out e "S" subshell in the "N" main shell. An example is is again potassium (Z = 19). Refer to figure

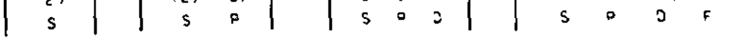


Figure 4

3. In the case of potassium, the "M" shell has shell full. The last electron would not ha the "D" subshell, so it was moved out to th In most cases, this will happen; this is no the law. A brief review of Table I, "Distr Electrons", will show that a number of elem from the above. The majority do have some least through the "M" shell.

G. Group (or column)

1. Each group or column on the "Periodic Chart contains atoms of similar behavior in verti ment, since the Roman numeral number is equ general, to the number of valence electrons the properties of the atoms. The Roman num head of each column indicates the column nu general the number of such outer electrons.

2. The grouping of the elements according to v electrons gives a ready reference to the el characteristics of the particular elements. elements all have a valence of one electron the "Periodic Chart", figure 1, that copper Group I; copper is a good conductor. On th end of the chart is Group VIII. Group VIII all the inert elements. Inert elements are elements whose outermost shell (or subshell shell) is full. These elements in Group VI readily combine chemically with other eleme will not give up or take on electrons; thus stable or inert - good electrical insulator

3. Groups I, II, and III are electrical conduc will readily give up an electron. These el give up an electron in an attempt to gain a and become chemically stable.

shell within a shell). The breakdown of the elements can be seen by referring to Table 1, bution of Electrons." Note that the "inert" s are underlined.

V is the "semiconductor" group. These elements ur electrons in their valence. They will either or give up electrons in an attempt to become lly stable. For this reason, Group IV elements ween conductors and insulators - semiconductor.

N

e last twenty years, literature on solid state researc
. The information accumulated regarding the copper
fier and germanium and silicon crystals led to the
of the transistor. A semiconductor, from which tran-
made, is an electronic conductor with resistivity in
etween that of a conductor and an insulator. The phe-
transistor action is unexplainable by electron theory
a new theory is used which is called hole flow. It is
hat the technician have a basic understanding of solic
cs in order to be able to understand the operation of

S. Kiver, Transistor and Integrated Electronics. New
.Y.: McGraw-Hill Book Company, 1972, Fourth Edition.

rg and Osterheld, Essentials of Radio--Electronics.
k, N.Y.: McGraw-Hill Book Company, 1961, Second
.

ction

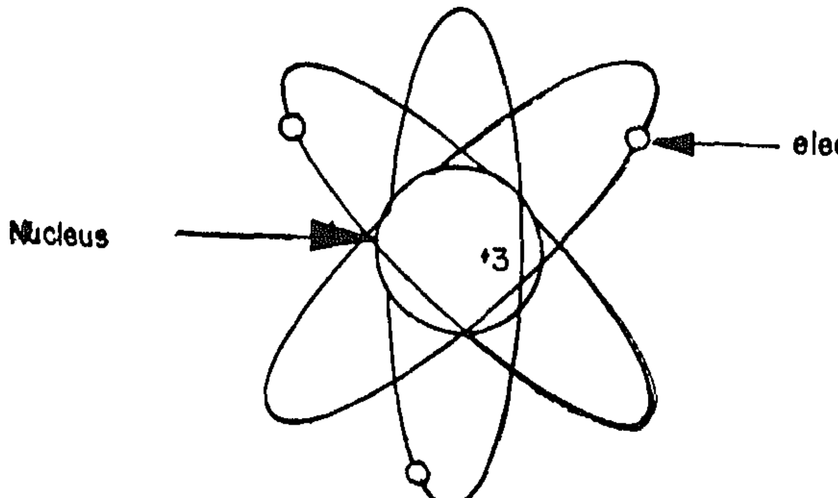
story of the transistor is, in large measure, the sto
matter and how the scientists at the Bell Telephone
oratories have been able to make that matter amplify
ctric currents. If we consider the vacuum tube as man
st significant advance into the field of communication
n the transistor must certainly be heralded as man's
ond most important step.

first public announcement of the transistor was made
e 1948. Thus, in terms of time, the transistor does
pare with vacuum tubes. In terms of application, how-
r, it must be classed with the vacuum tube. And while
re is probably no prospect that it will completely re-

D. Operation of vacuum tubes depends upon the flow trons from cathode to plate and the control of intermediate grids. Operation of the transisto dent upon electron and hole flow. These two de perform the same functions, but there are consi differences between the two. In order to appre differences, a study of atomic structure, intri materials, and electrical properties of semicon required.

II. Review of atomic structure

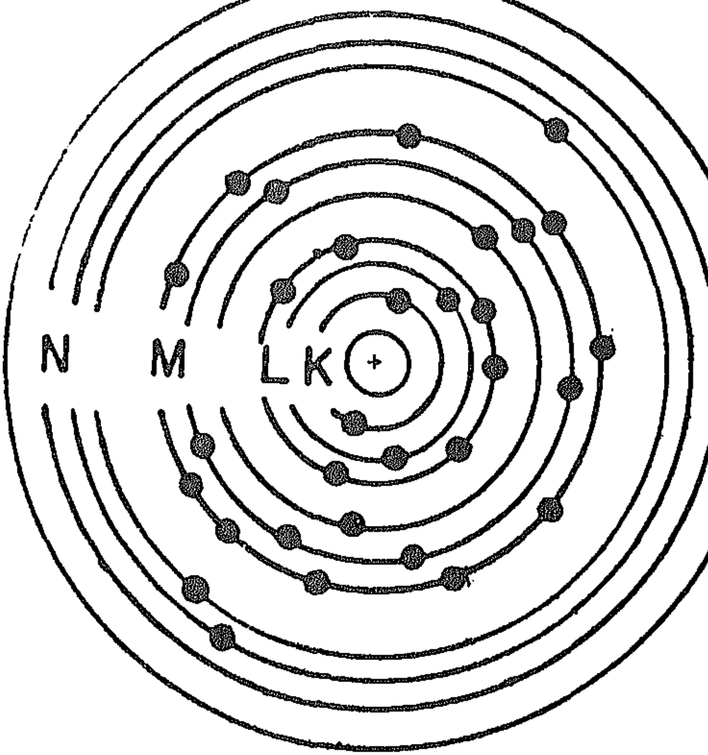
A. Any atom may be considered to be composed of a located nucleus surrounded by electrons, which various orbits (see figure 1). The nucleus con neutrons, which have no electric charge, and pr are positively charged. Neutrons and protons h tially the same weight, and the combined weight neutrons and protons is referred to as the rela weight of the element. The number of protons w nucleus determines the atomic number of an elem net positive charge on the nucleus. If an atom usual atomic number, but a different atomic wei it contains an abnormal number of neutrons, it isotope.



me higher energy level to one which is closer to the
. Conversely, an electron excited from an inner to
r orbit will absorb energy. If by some means
e electric fields, high temperatures, radiation,
etc.) the total energy of an electron is increased,
ectron will be torn from the parent atom. Under
onditions, ionization or breakdown has occurred.

ns have been found to surround the nucleus in shells
n in figure 2 and the manner in which they are dis-
is:

in Shell		Sub Shell	
K	2 electrons	2	electrons
		s	p
L	8 electrons	2	6 electrons
		s	p d
M	18 electrons	2	6 10 electrons
		s	p d f
N	32 electrons	2	6 10 14 electrons

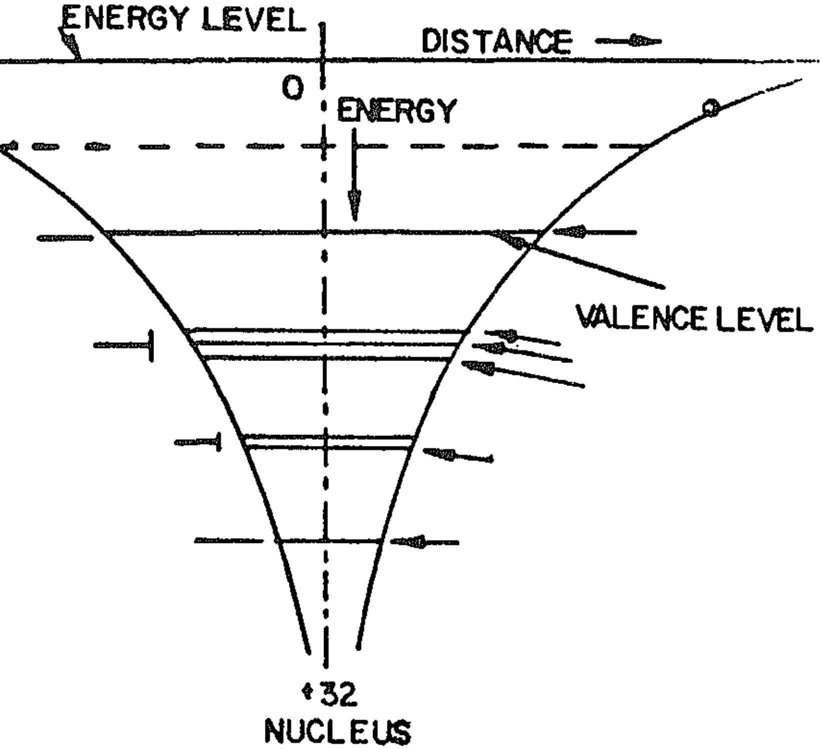


A two dimensional representation of the mann
which electrons are distributed about the nu
of a germanium atom.

Figure 2.

E. Electrical and chemical activity of a materia
stricted to the electrons in the outer shell.
shell of an atom is called the valence shell
occupying orbits in these shells are called v
electrons. Unfilled orbits lying above the v
are called excitation levels. Imparting suff
to an electron may cause it to jump into an e
level. The applied electric field may cause
by a displacement process toward the region o
tive potential. Actually, at temperature abo
zero, there will be some probability of findi
in the excitation level because of thermal ag
we shall see later, this is one of the most s

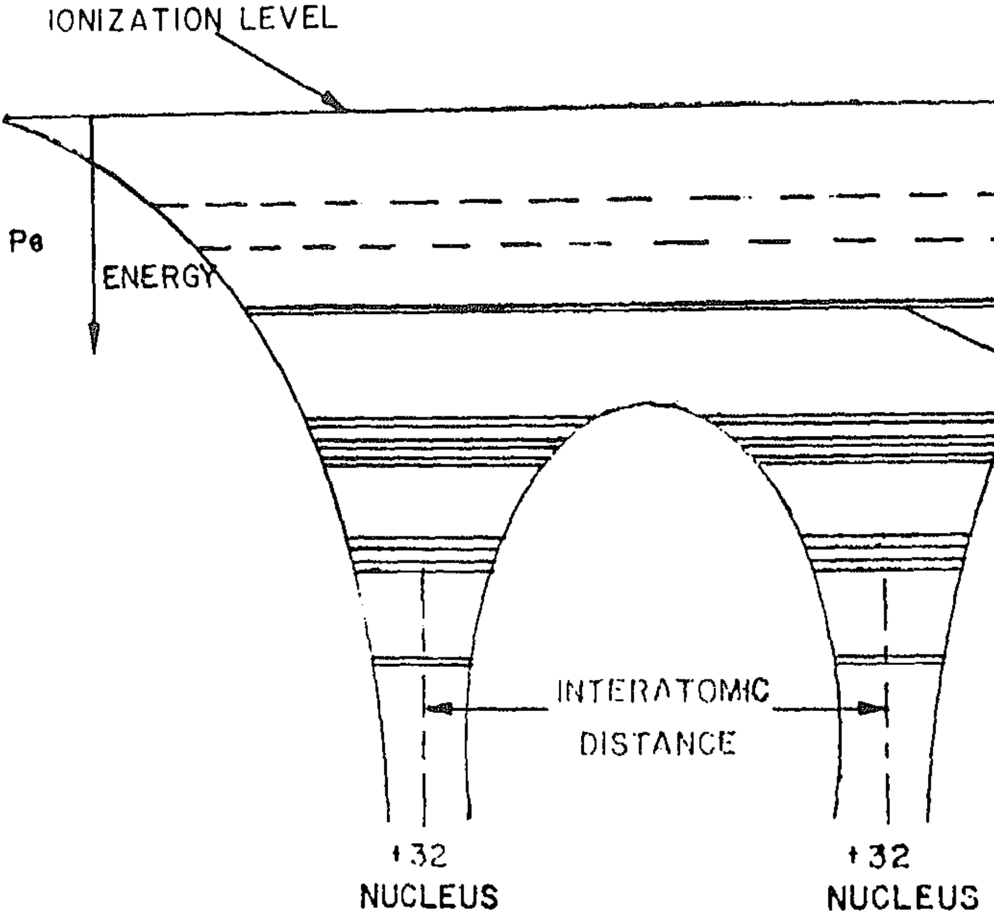
electrons. Silicon has an atomic number of 14, eans there are 2 electrons in the K shell, 8 in the 4 in the M shell; therefore, silicon has 4 valence ns. A plot of the total energy of an electron as tance from the germanium nucleus increases, is shown re 3.



ution of energy levels for a germanium atom.

Figure 3.

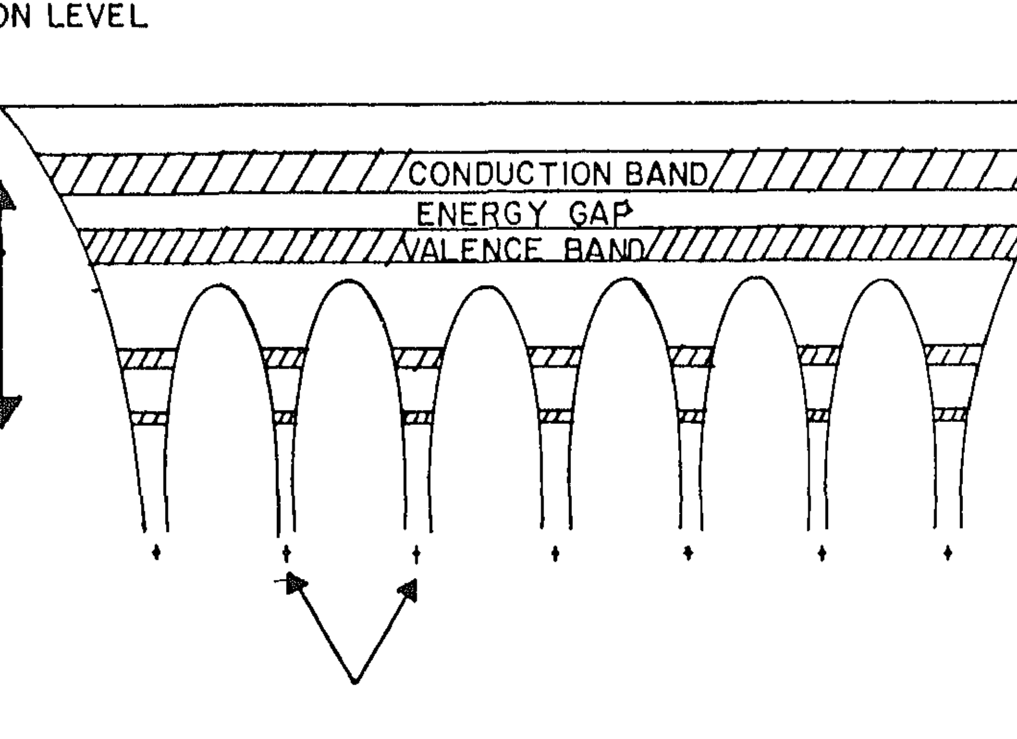
an electron in one atom is ... counterpart in the other atom has a slightly ... energy level, and they can switch levels conti... Note in figure 4 that the valence and excitati... common to both atoms. This means a valence el... atom could travel to another and vice versa wi... requiring any external energy.



When two similar atoms are brought together, a... action occurs which permits additional levels.

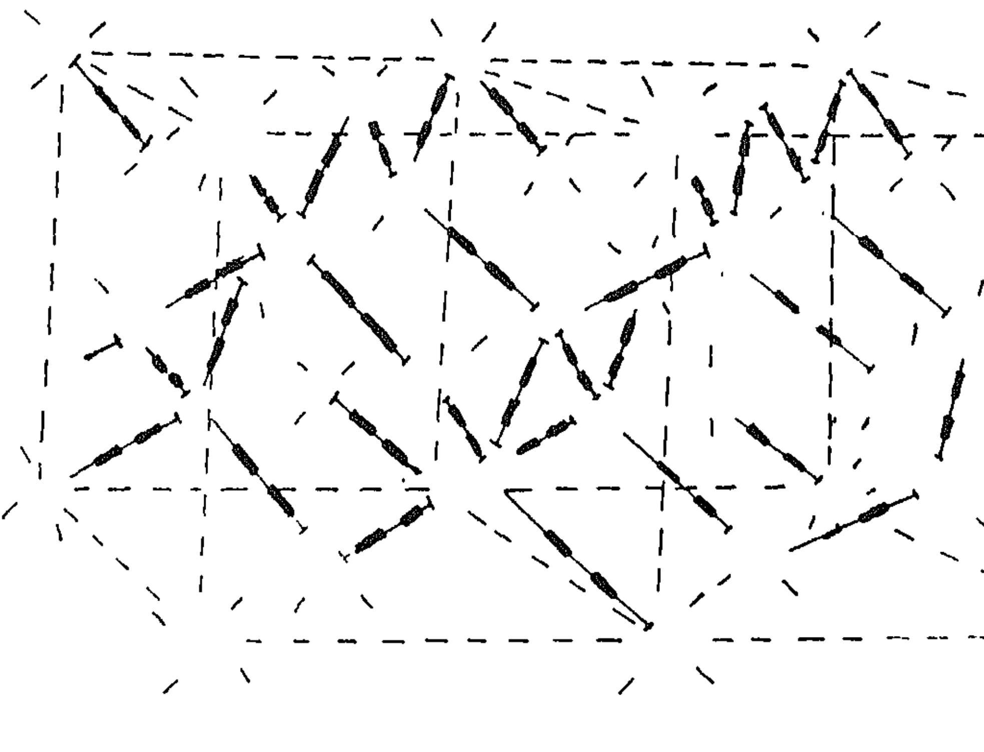
Figure 4.

The various valence levels form the valence band. Th
first excitation levels are lumped into the conductio
band. For conduction to occur when an electric field
applied to the crystal of figure 5, electrons must be
accelerated in order to change their total energy. B
because of their discrete behavior their total energy
increase only if they can be excited into a new level
in a crystal, the valence band is completely filled,
duction can occur only when sufficient stimuli is imp
to raise some electrons from the valence band to the
duction band. Here there are many levels through whi
electron may be accelerated. Note that accelerating
electron from the valence band into the conduction ba
leaves a vacant level in the valence band. This mean
electrons can now accelerate in the valence band. Th
vacant level left in the valence band is a hole.



adjacent atoms to form pairs of shared elec
electron sharing is called covalent bonding
covalent bonds bind the germanium atoms int
orderly, geometric pattern within the cryst

2. Figure 6 is a simplified illustration of th
arrangement of a crystal structure. The in
of each atom has an overall positive charge
locked into the structure in an orderly man
ion is repelled by the similarly charged su
ion from various directions, thereby stabil
positive of the ion in the structure. The
large mass of the ion also contributes to t
stability.



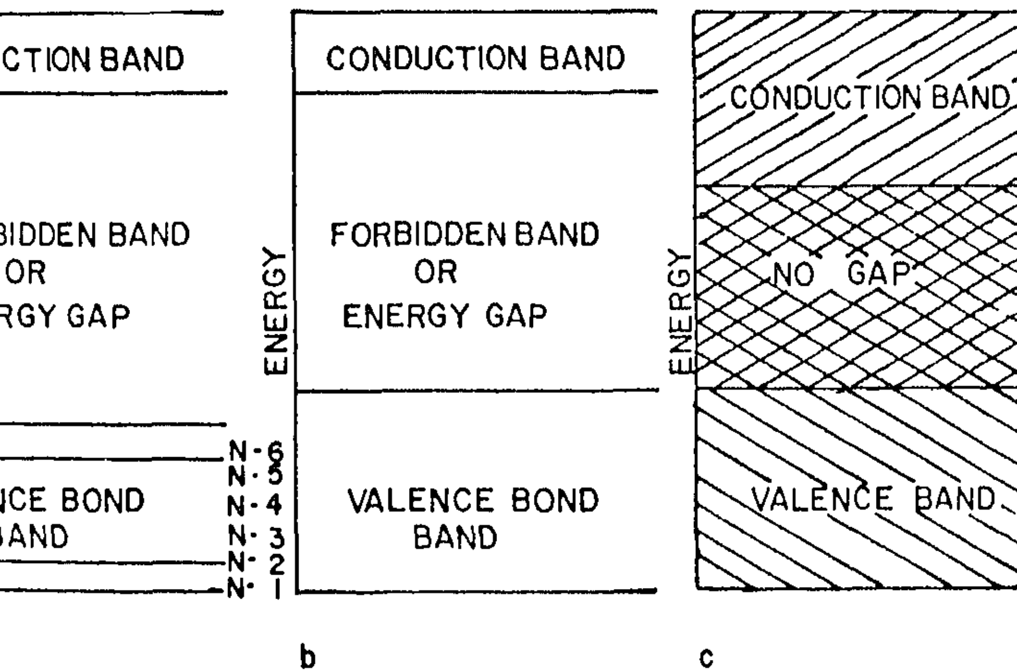
Pure germanium crystal, lattice structure.

Figure 6.

3. Materials may be broadly classified as insu
semiconductor, or conductors according to t

Insulators

a. An insulator may be defined as a material which offers high resistance to the flow of electrons. The basic reason for offering such a high opposition to the flow of electrons is that free electrons are relatively scarce in such materials. referring to figure 7(a), which illustrates the energy diagram of an insulator's valence and conduction band, it can be seen that the energy gap wider than that of the semiconductor and conduct The energy levels within the insulator's valence band are filled, and the energy levels in the conduction band are empty. This means the valen electrons have very little opportunity to underg changes from one valence energy to another.



Energy bands: (a) insulator (b) semiconductor

motions, and virtually no mobile ele
available for participation in the c
process.

5. Semiconductors--Figure 7(b) is the energ
semiconductor. The energy levels withi
band are filled, as in the case of insul
valence electrons have very little oppo
change levels in the valence band, since
vacant levels. The forbidden gap betwee
and conduction band is not as great as
insulator. The probability of valence e
acquiring the necessary increment of the
better, since smaller packages of therma
required. This energy gap, at room tem
about 0.7 eV for germanium and 1.2 eV f
Because of the lower height of the forbi
gap, semiconductors have resistivity lo
tors, but considerably higher than cond
<u>electron</u> <u>volt</u> (eV) is the Kinetic energ
electron when accelerated through a one-
difference.

6. Conductors - The energy diagram of a co
in figure 7(c). Notice the overlap bet
valence levels and lower conduction lev
electrons, in such a material, require
increments of thermal energy to be exci
conduction level. The probability of t
occurring at room temperature is very h
material displays low resistance (high
Such is the condition which exists in m
conductors.

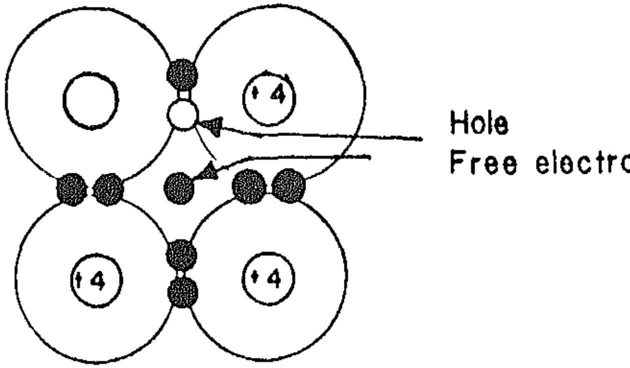
*Conductivity is the reciprocal of resistivity; or,

astically alter their electrical properties. For this
ason, a semiconductor would not be called truly intrin
less the impurity level is very small--for germanium l
an 1 part impurity in 10^8 parts of germanium; for sili
e impurity content would have to be less than 1 part i
^{12}. In practice, however, semiconductor material with
mewhat larger impurity concentrations than these is st
metimes referred to as intrinsic.

temperatures of absolute zero, intrinsic germanium or
licon can be shown as it is in figure 6. All of the
lence electrons are tightly held by the parent atoms a
so, through the covalent bonds by other atoms. The
ectrons are not free to move through the crystal struc
re and, thus cannot conduct electricity. For this
ason, an intrinsic semiconductor at absolute zero beha
ke an insulator. It is a very poor conductor of
ectricity.

nsider what happens as the temperature is increased.
crease in temperature means an increase in the heat en
each atom. This increase in energy may be given to o
the atom's valence electrons. By this process, a val
ectron may acquire sufficient energy to break away fro
s parent atom and, in so doing, break one of the coval
nds. This electron is now free to wander through the
ystal structure and is not bound to any particular ato
is called a free electron and can now act as a curren
rrier if a voltage is applied to the material. A curr
rrier is simply any charged particle (such as an elect
ich is free to move as part of an electric current if
urce of voltage is applied.

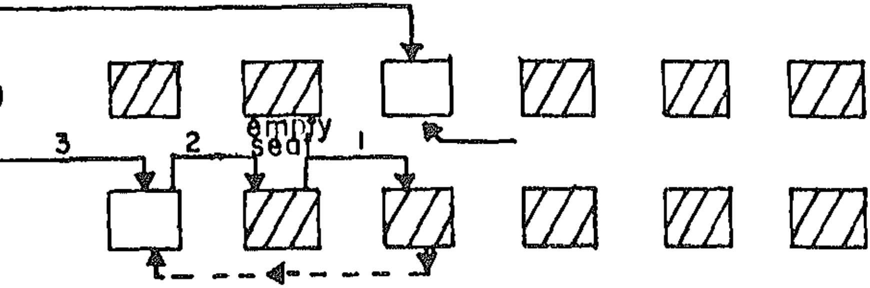
t what happened back at the place where the electron l
s parent atom? It left behind a vacancy or an incompl
valent bond, which is usually referred to as a hole.
gure 8 shows the crystal structure with one free elect
d one hole brought about by the electron breaking away
om the parent atom. This process of the formation of
ectrons and holes is called thermal generation.



Creation of a free electron and a hole caus
by an increase in crystal temperature.

Figure 8.

E. The interesting thing about a hole is that it
current carrier. If a hole is created by an e
breaking away in one atom, an electron from a
atom can easily fill the hole by breaking its
bond and jumping over to the first atom. Whe
it appears that the hole has moved. If you ha
and an electron at B, when the electron fills
it leaves a hole at B. Thus, in effect, the h
from point A to point B. This can be illustra
sidering the situation when you arrive late a
and find the only vacant seat is in the cente
(see figure 9).

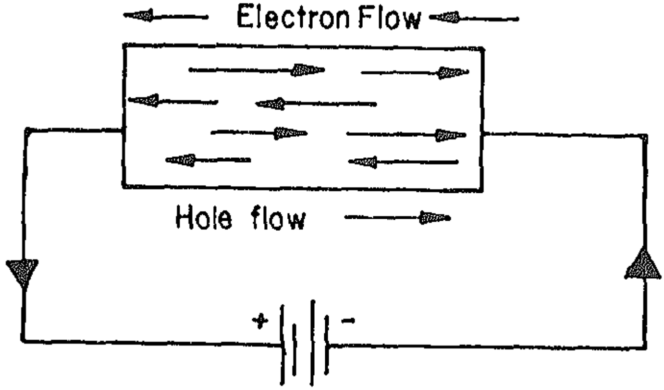


Hole movement.

Figure 9.

you can become a "free electron" and go along the row
ou get to the "hole" or the people in the first two
an move in sequence one seat to the right and make the
move to you at the end of the row.

e a hole exists there is a net positive charge
the +4 charge of the parent atom (nucleus and inner-
lectrons) is greater than the -3 charge of the three
ng electrons. Thus, we consider the hole as having,
ct, a positive charge. When the hole moves, there is
of positive charge. A voltage is applied to a semi-
or containing free electrons and holes, the free
ns will move from negative to positive, and the holes
ve from positive to negative. Remembering the dis-
of hole movement, you can see that a hole moving to
ht is really an electron moving to the left. Thus,
w of holes from positive to negative is really the
the flow of negative charges (electrons) from
e to positive. You can think of current in a semi-
or as consisting of two parts; free electrons moving
opposite direction. To get the total current, you
d tne two parts. Figure 10 is a representation of
w of charges in a semiconductor.



The flow of charges in a semiconductor due to an applied voltage.

Figure 10.

The flow of charges in a semiconductor due to an a
voltage. NOTE: There is no hole flow external to
conductor. Current flow in a conductor is by the
of free electrons.

You may be wondering what happens to the holes whe
reach the edge of the piece of semiconductor mater
B in figure 10). The answer is that some of the e
coming from the negative battery terminal combine
fill the holes so that both the holes and the fil
electrons disappear as charges. This process is c
combination. The rest of the electrons travel thr
semiconductor as free electrons. The electrons le
A) fall into one of the two categories: those whi
at B and traveled through the crystal or those whi
freed within the crystal when the holes were forme

ole current, jump from "hole to hole and do not have en
o become really free. On the other hand, the free elec
rons have enough energy to move freely through the crys
ithout being tied down to any atom.

ou can see from this that the free electrons are able
ove faster through the crystal than the holes, which ha
o move in a succession of jumps. We say that the free
lectrons have a higher mobility than the holes.

t ordinary room temperature (approximately 25°C), the
hermal energy is sufficient for a large number of free
lectrons and holes to exist in an intrinsic semiconduc
t room temperature intrinsic semiconductors such as ge
anium and silicon are fair electric conductors, being
poorer conductors than a metal such as copper, but much
etter conductors than an insulator such as rubber. An
mportant characteristic of an intrinsic semiconductor
hat is possesses a negative temperature coefficient (re
istance decreases with a rise in temperature); therefo
onductivity increases with an increase in temperature.
his is true because of the increased thermal agitation
igher temperatures; therefore, there are more free ele
rons and more holes created. In an intrinsic semicond
ith no applied voltage, the total number of free elect
quals the total number of holes.

(extrinsic) semiconductors

ractical semiconductors contain traces of impurities
eliberately added to the material after the natural
mpurity level has been reduced to a negligible degree.
he types of added impurities fall under two categories

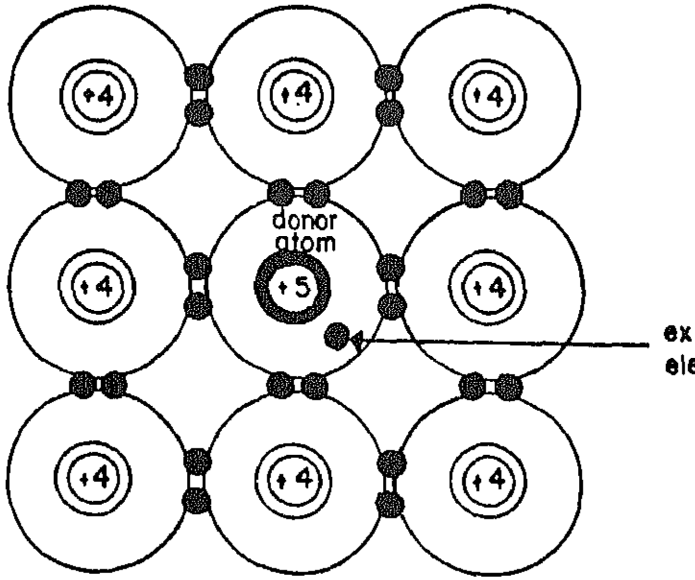
. Elements containing five valence electrons (Pentava

. Elements containing three valence electrons (Trival

he effects of each type upon the energy and electrical
haracteristics of germanium will be examined.

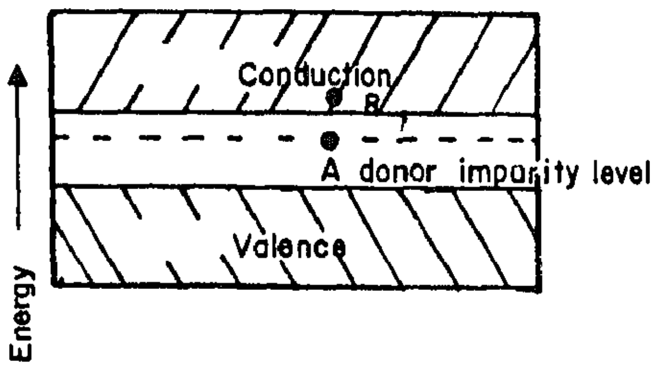
he donor or N-type crystal

. There are a number of elements possessing five elec
in their outermost shells which are chemically comp



The additon of an N-type impurity ato
produces one free electron.

Figure 11.

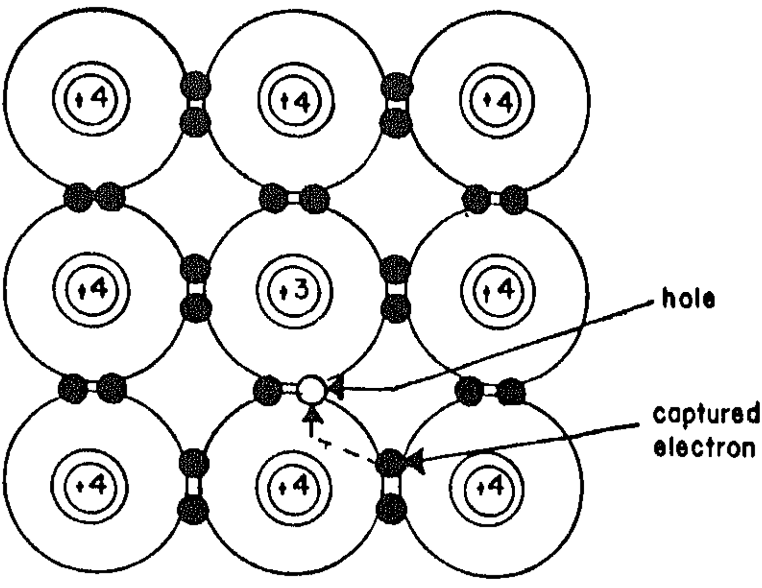


Energy distribution in donor-type germa

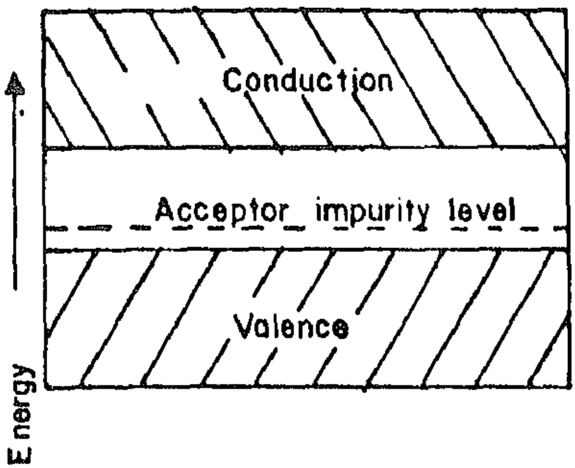
temperature is approximately 0.026 eV.

3. A crystal containing an impurity whose atoms posses[s] five valence electrons is called a donor crystal, [s]
it readily donates electrons to the conduction proc[ess].
The conduction which occurs because of these mobil[e]
electrons, when an external electric field is appl[ied]
is called extrinsic conduction, as opposed to intr[insic]
conduction which is due to electrons that are elev[ated]
to the conduction region from the valence energy [band].
Because of the great difference in energy requirem[ents]
between the two types of conduction, extrinsic con[duc-]
tion occurs at a much lower temperature than intri[nsic]
conduction (where the increment of energy must be [at]
least as high as the forbidden energy gap). At a [given]
temperature the conductivity of the donor crystal [is]
higher than that of a pure crystal to an extent de[ter-]
mined by the number of impurity atoms added. The [majority]
carriers of charge in this type of material are ne[ga-]
tive, hence the term N-type crystal.

acceptor or P-type crystal



electron from another atom to complete its
arrangement, and any such three-valence el
"<u>acceptor</u>" atoms. When the gallium atom h
more electron than it should normally have
negative ion. This extra electron must be
distance form the gallium nucleus than the
valence electrons and is therefore closer
band in terms of energy. The energy level
electron is immediately above the valence
in figure 14.



Energy distribution in acceptor type ge

Figure 14.

B. Notice that only a small increment of ene
(0.01 eV) to excite a valence electron in
impurity energy, since this level is clos
band than the conduction region. This ac
even at low temperatures, where relativel
electrons are thermally excited across th
energy gap. Each valence electron excite
impurity level leaves a vacancy (hole) in
band, so it is possible for valence elect
covalent band and move to another with th

ifting toward the negative terminal of the external
ial. Within the extrinsic range of temperatures, at intrinsic conduction is negligible, the significant n of conduction occurs by this hole current in the semiconductor. Actually, the major cariers of charge s material are positive, hence the term P-type nductor.

rical properties of semiconductor materials

ivity

e electric resistance of a piece of material depends its atomic structure; on the material length; and on s cross-sectional area. Resistance can be expressed thematically as:

$$R = \frac{PL}{A}$$

ere R, L, and A are resistance, length, and cross-ctional area, respectively, and P is the resistivity pecific resistance) of the material. The reciprocal resistivity is conductivity. Resistivity is a asure of the degree that a material opposes the flow electric current, and conductivity is the degree that material allows current to flow. A material which hibits a high opposition to current flow is said to ve a high resistivity. The same material could also said to have a low conductivity.

e manner in which a semiconductor device behaves in an ectronic circuit depends greatly on its resistivity, ich can be controlled over a wide range. The value of sistivity (or conductivity) of a semiconductor depends : the charge on each carrier; the concentration of rrent carriers (holes and electrons); and the carrier bility (ease with which carriers may be moved).

e charge on a hole is always +1 and the charge on a ee electron is -1. These values cannot be changed. us, carrier concentration and carrier mobility are the operties that may be changed to alter resistivity. In neral, it is desirable to make carrier mobility as gh as possible. This leaves carrier concentration as

free electrons is equal to the number of
value of the free-electron concentration
concentration) in an intrinsic semicondu
the intrinsic carrier concentration. Th
creases exponentially with an increase i

B. Thermal generation and recombination

1. When a semiconductor is exposed to a tem
absolute zero, some of the heat energy a
material may be acquired by an electron,
the conduction band and leaving behind a
produces two charge carriers: one hole
electron. They are said to have been th
generated. As long as the material is e
temperature, the free electrons and hole
continuous random motion even though the
current flow.

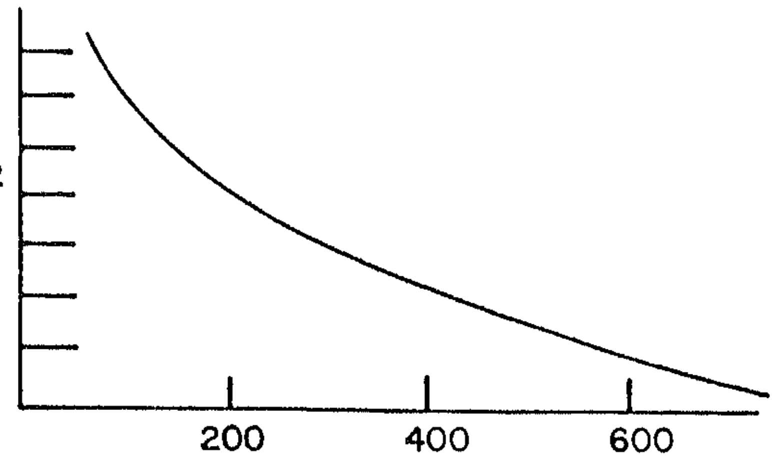
2. This may be likened to a swarm of bees a
Each bee moves rapidly from place to pla
but if no new bees are arriving and none
the net flow of bees is zero, although t
continuous motion.

3. The rate at which hole-electron pairs ar
erated depends on the temperature and on
the forbidden energy gap in the crystal.
recall that germanium has a smaller ener
silicon. Consequently, at a given tempe
thermal generation rate will be higher i
in silicon, because it takes less energy
electron from germanium's valence band t
band.

4. As a free electron moves randomly throug
structure, it may encounter a hole and b
valence electron. When the electron com
hole, the hole no longer exists and the
longer free; hence, two carriers cease t
process is called recombination.

5. The rate at which recombination takes pl
the number of holes and free electrons i

vity will decrease (conductivity will increase) ore carriers are present to conduct current. ntrinsic carrier concentation increases with ture, resistivity decreases, and conductivity ses. A typical plot of intrinsic resistivity temperature is shown in figure 15.



Variation of resistivity with
empeature for intrinsic silicon.

Figure 15.

rinsic semiconductors, the number of free elec- is not equal to the number of holes. In N-type als, each donor atom contributes a free electron t contributing a hole. The only holes present are produced by thermal generation. The thermally ted holes are called minority carriers. Simi- in P-type materials, the only free electrons t are those thermally generated, and the number of present is equal to the number created by the or impurity plus the number generated. The lly generated electrons are called minority rs.

increased, the concentration of thermal
carriers may become comparable with tha
impurity-produced carriers, and the res
become temperature-dependent. If the t
semiconductor is increased to such an e
thermally generated carriers greatly ou
impurity-produced carriers, properties
will be mainly dependent on the interna
generated carriers, and the material wi
intrinsic.

10. Resistivity of extrinsic germanium or s
temperature is determined almost comple
amount of impurity present in the mater
limits, any desired value of resistivit
by adding the correct amount of impurit
formation of the crystal.

C. Mobility

1. It hs been stated that mobility is a me
with which the carriers can be made to
material. It is measured as the rate o
carrier (in centimetes per second) per
field (1 volt per centimeter). Thus, m
dimensions centimeters per second divid
centimeter, or cm^2/volt-sec.

2. Although mobility does not appear to be
from resistivity considerations, it pla
important role in the behavior of semic
In semiconductors, the mobility of the
greater than the mobility of the holes
it is easier to move a free electron in
band than it is to move a bound electro
the valence band. (Keep in mind that t
electrons in the valence band from hol
brings about the movement of holes.) S
can be made to move by the application
idea of "hole mobility" is not unreaso

[illegible]	[illegible]	[illegible]	cm^2/volt-sec
ility	1,900	500	cm^2/volt-sec
c Resistivity	65	200,000	ohm-cm
ap	0.7	1.1	eV

rinsic properties of Germanium
Silicon at room temperature.

TABLE 1.

several factors affect the carrier mobilities, re of the crystal structure through which the move has the predominat effect. Any impuri- imperfections in the crystal lattice tend to arrier motion. If the structure is perfectly all atoms are in their proper places and no oms are present. The carriers can move easily the structure and mobility is high. However, if tions exist in a crystal, the movement of is retarded and mobility is reduced. The types fections that can exist in a crystal structure too numerous to delve into at this time. it to say that one of the most important steps anufacture of semiconductor devices is the of crystals with as nearly perfect lattice e as possible.

ure is another factor that affects mobility. At eratures, atoms in the crystal structure tend to their regular places. As temperature is d, energy is added to the crystal. Some of this s used to excite the electrons to the conduction t some of it is also given to the atomic cores, them to move very slightly. Although the cores ove away from their positions, they do vibrate ut of position much as a violin string vibrates leaving the violin. This vibration has the f impeding carrier motion.

concentration than it has on mobility.

D. Diffusion currents

1. It has been determined that if a voltage
piece of semiconductor material, the hol
negative terminal and the electrons to t
terminal. The combined effect of this m
and electrons constitutes a current.

2. It is possible for a current to flow in
even in the absence of an applied voltge
tration gradient exists in the material.
tration gradient occurs when the concent
type of carrier is greater in one part o
ductor than it is in some other part.

3. When a concentration gradient of carrier
or free electrons) exists in a material,
tend to move from the region of higher c
the region of lower concentration. The
said to diffuse from the region of high
and the current produced by this movemen
diffusion current.

4. Consider a small bar of P-type semicondu
which the charges are evenly distributed
length of the bar. The concentration of
electrons are in equilibrium and no grad
Suppose that a large number of electrons
carriers) is injected at one end of the
is accompolished will be discussed in PN
theory.) These added minority carriers
concentration of electrons at the end wh
injected than in the rest of the bar. H
tron gradient exists. The excess electr
toward the other end of the bar, attempt
uniform distribution throughout the bar.
results in a diffusion current. The rat
electrons diffuse, and hence, the diffus
depends on the value of the gradient and
of the electrons.

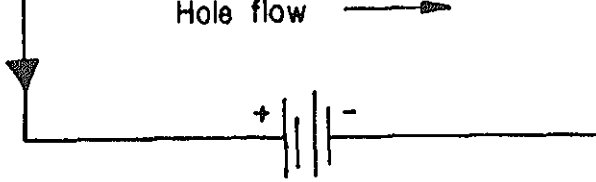
ess carriers disappear by recombination. The length time required for the excess carriers to disappear by combination is called the Lifetime of the excess riers.

have seen that two distinct things occur when excess ority carriers are injected into a material. The riers diffuse and they recombine with the opposite-e carriers. Consider these two occurrences simulta-usly. Imagine, again a high concentration of free ctrons injected at one end of a P-type semiconductor . The electrons diffuse toward the other end of the and, at the same time, recombine with holes. As y move along the length of the bar, more and more of m disapper by recombination. Eventually, all of the ess electrons will disappear, but in the meantime y have moved along the bar; the distance the ctrons move before they disappear is called the fusion length of minority carriers. If excess holes injected into an N-type material, the holes will ergo the same sort of process as free electrons.

can see that the diffusion length of minority riers in a material depends on how fast the carriers e and on how long they move before disappearing; that diffusion length depends on mobility and lifetime.

nd behavior of the PN junction

been brought out in the information sheet, "Intro- to Semiconductors," that when a voltage is applied emiconductor, current flow is brought about as a of holes moving toward the negative terminal and ons moving toward the positive terminal (see figure



The flow of charges in a semiconduc
due to an applied voltage.

Figure 16.

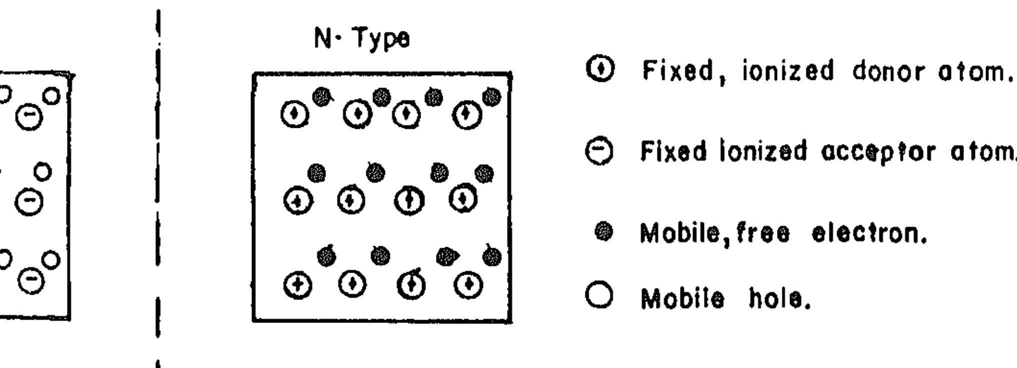
The total current is the sum of the curr
hole flow and the electron flow. It is
current. A second current may exist in
This current, called diffusion current,
result of a gradient of a carrier concen
diffusion current may also be due to bot
flow. The hole and electron flow is in
and the total diffusion current is the s

B. A material which contains an equal numbe
negative charges is said to be electrica
Objects which are electrically neutral d
electric charges. An ordinary atom is e
since it has as many negative charges (e
positive charges (protons). When an ato
it is left with a net positive charge an
tive ion. When an atom gains an extra e
net negative charge and is called a nega

C. A sample of semiconductor material is no
neutral since it is made up of atoms whi
electrically neutral. Although a free e
away from the atom (leaving a positive i
inside the semiconductor material, the s
electrically neutral. If a current flow
due to an applied voltage, electrons are
the material at the positive terminal an
electrons are entering (at the same rate
terminal. The semiconductor remains ele
during conduction when considered as a s
ever, if for some reason, a semiconducto

and another object becomes negatively charged, a
l difference (or voltage) will exist between them.

an N-type semiconductor such as silicon. Each
atom consists of a core with a net charge of +4 and
ence electrons, each with a charge of -1. Thus, the
atom is electrically neutral. Each donor atom has a
h a net charge of +5 and five valence electrons each
harge of -1. Only four of these valence electrons
in bonding with the silicon atoms. The fifth
is free to wander around. As it moves away from
r atom, it leaves behind a positive ion with a net
f +1. The positive ion is not free to move, as it
in the crystal structure. Thus, an N-type semi-
r is studded with immobile positive donor ions and
egative electrons. In a similar way, P-type silicon
egarded as a neutral material studded with immobile
acceptor ions and mobile positive holes. Figure 17
tes the charge distribution in separate P-type and
amples.



arges in separate P-type and N-type materials

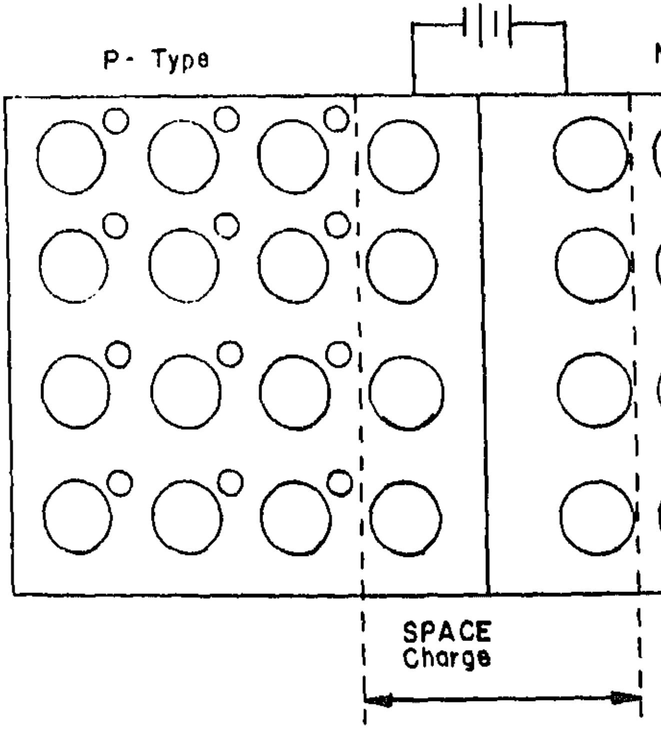
s in separate P-type and N-type materials.

Figure 17.

con atoms are not shown and should be imagined as a
us crystal structure over the whole background. The

it will allow current to flow through i
direction.

E. we now turn to the condition of the mat
the junction is formed. (We shall take
assuming that we can merely push the tw
form the junction.) A completely diffe
ditions will now exist. In the P regio
concentration of holes. Since the hole
P side is so much greater than that on
will diffuse into the N region. The di
similar to the uniform distribution of
glass of water after an ink drop has be
ink molecules try to distribute themsel
technical parlance, we say that a hole
gradient exists from the P to N region.
electron concentration gradient exists
region and results in electrons diffusi
tion. See figure 18.



a unneutralized positive ion. These unneutralized, imm
ile ions on each side of the junction are called uncove
harges, and the electric field between them can be con-
eniently represented by a battery placed across the
unction as shown by the dashed lines in figure 18.

he holes that cross from the P to the N region recombin
ith electrons on the N side. Simarly, electrons from t
region recombine with holes on the P side. This flow
oles from the P to N side and electrons from the N to t
side constitutes a recombination current across the
unction. This recombination current does not, however,
ersist at some constant value. Instead it falls to som
ery low value vicinity of the junction. The uncovered
egative ions on the P side start repelling the electron
rom the N side while the wall of uncovered positive ion
n the N side repels the holes from the P side. The bat
n figure 18, therefore, represents the barrier potentia
et up by the uncovered charges, which inhibits the re-
ombination currents. Thus, it seems that a condition
quilibrium is established between the diffusive potenti
f the concentration gradient, the barrier potential of
oncentration gradient and the barrier potential of the
ncovered charges.

f thermal agitation caused all the mobile carriers to h
xactly the same kinetic energy, this simple explanation
quilibrium conditions at the barrier would suffice. Ho
ver, the thermal energy impaired to the mobile charge
arriers is randomly distributed. Statistically speakin
ome holes and electrons have only a small amount of kin
nergy whereas others have a very large amount. Some of
igh energy carriers will, from time to time, be capable
vercoming the barrier potential. If this were the only
ction, it would seem that the barrier height would keep
ncreasing in an effort to compensate for those high-ene
arriers that manage to hurdle it. Ultimately, we might
xpect the last of the mobile charges to cross the barri
eaving some large barrier potential.

carrier, and it will have some average time of
lifetime) before it combines with one of the nu
available. The lifetime of a minority carrier
depends upon the number of surrounding majority
which, in turn, is determined by the number of
atoms introduced into the lattice.

J. If this electron in the P region survives long
drift into the vicinity of the junction, it wil
the influence of the electric field existing th
direction of the field is such that the electro
swept across the depletion region (region conta
uncovered charges) since it is attracted by the
positive ions on the N side. Another way of vi
this is to imagine the barrier battery in figur
electrons from the P to the N side.

K. By similar reasoning, we see that a thermally g
in the N material constitutes a minority carrie
be swept across the depletion region from the N
side. The flow of thermally generated minority
across the junction is aided by the potential b

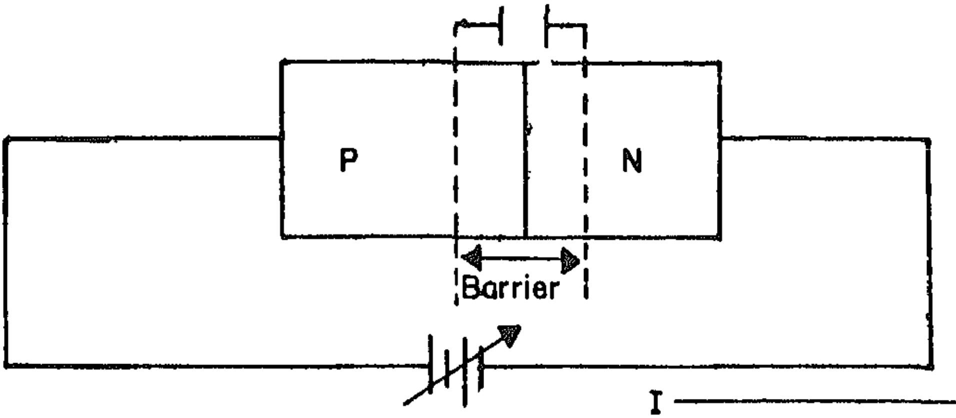
L. We now have a complete picture. With no extern
applied, the actual equilibrium conditions are
There will be a net recombination current acros
tion which consists of holes climbing the barri
P to the N side and electrons which climb the b
the opposite direction.

M. At the same time, the breaking of covalent bond
a net thermally generated current because the m
carriers are swept across the barrier. The the
erated current (minority) depends solely upon t
The net result is that the total junction curre
which it must be, since shorting a PN junction
of wire does not result in a current flow throu
The barrier height will assume a potential of s
that it permits the recombination current to ju
thermally generated current.

will be higher due to the increased concentration of
and acceptor atoms. Overall, the barrier will become
narrower.

ward bias

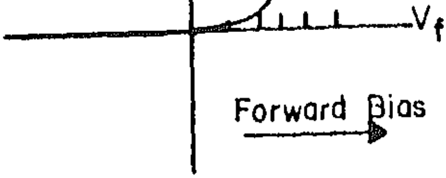
Consider that an external source of potential is conn
to the PN junction, as illustrated in figure 19.



The PN junction with forward bias permits
large amounts of current to flow.

Figure 19.

Placing the voltage source across the diode causes an
electrical field which opposes the barrier potential
(positive to P-type and negative to N-type material)
established through the semiconductor. This is known
forward bias. The net effect is that the height of
barrier is reduced. For convenience, we might think
external source as trying to push holes from the P to
region and electrons from the N to the P region. The
mechanism involved is, however, not one of pushing but
merely controlling the net barrier potential. If we
the source from one potential to a higher potential,
shall find that the current increases quite rapidly a
some exponential curve. (Refer to figure 20.)



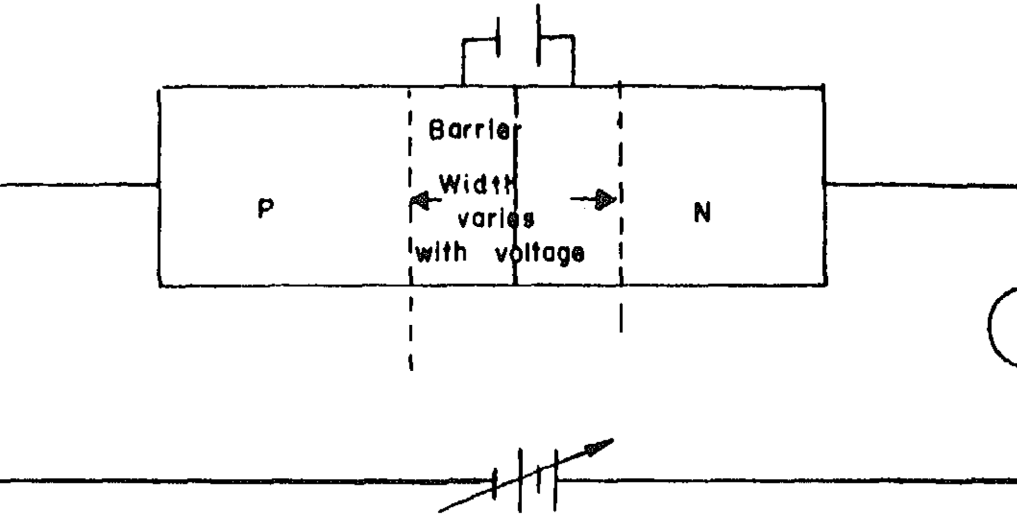
Forward bias characteristics.

Figure 20.

What is happening is that, in reducing the barrie
the recombination current greatly increases becau
holes from the P region and electrons from the N
cross the junction and recombine. The thermally
current does not significantly change, for it is
determined by the temperature and not the voltage
in the forward bias case, recombination current i
greater than thermally generated (minority) curre

B. We might be tempted to think that putting a volt
across the junction would annihilate the barrier
an enormous current flow. This does not occur be
the current increases, more and more of the appli
is used up as a voltage drop across the bulk of t
regions. The barrier can be reduced but not dest
attempt to reduce the barrier excessively will re
destruction of the semiconductor materials due to
dissipated in it.

C. Once the internal barrier potential is greatly re
the applied forward bias voltage, the current bec
limited, only by the source resistance of the app
source, the junction lead resistance, and the bul
tance, and the bulk resistance of the semiconduct
materials. The semiconductor material resistance
amount of doping, cross-sectional area and length
bulk resistance (about 1 to 200 ohms) can cause e
current flow; therefore, a current limiting resis
be placed in series with the semiconductor under
bias conditions.



Reverse bias connection.

Figure 21.

n this case, we see that the field established through
emiconductor by the external battery is such at it tend
.d the internal potential barrier in keeping carriers f
rossing to the junction. Mobile holes in the P region
rawn away from the junction toward the negative battery
erminal. Mobile electrons in the N region are also dra
way from the junction toward the positive battery termi
he more reverse bias that is applied, the wider the de-
letion region grows. If, as is usually the case, the P
sides are unequally doped, the depletion region will e
end further into the region of higher resistivity (mate
ith least doping). This is easy to understand if we
isualize the P and N regions are two resistors in serie
larger percentage of the applied voltage will appear
cross the larger resistor. This effect is important in
ransistors, for it results in a condition known as pun
hrough.

of reverse bias, the recombination curruent is
and current essentially equals the thermally g
currents (minority).

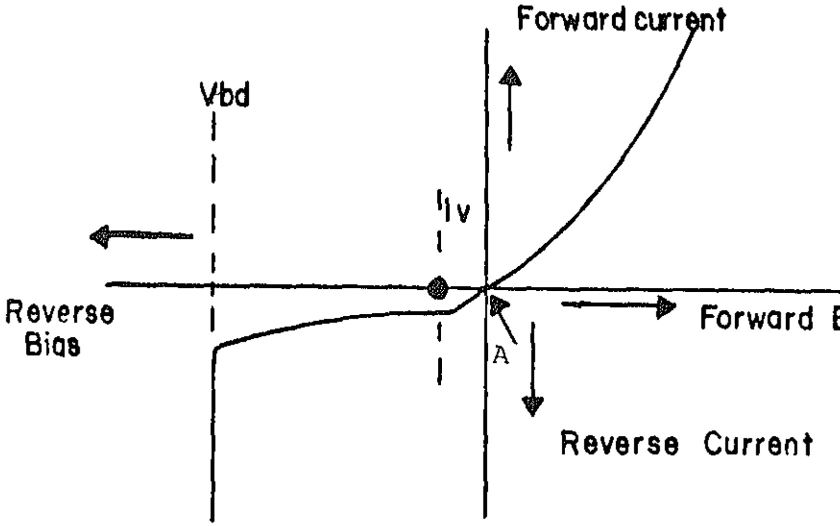


Figure 22.

C. As the reverse voltage is increased, it seems
reverse current remains constant since it is c
ture and not voltage dependent. However, the
that between -.1 volt and Vbd (voltage breakdo
reverse current actually increases with revers
Such a characteristic should be expected if th
leakage resistance in shunt with the junction.
resistance is due to dirt or other impurities
junction and little understood surface effects
tribute to leakage resistance.

little a 100 micromicroamps at room temperature becau
e energy gap in silicon is higher than in germanium an
erefore, at a given temperature, fewer electrons are
cited out of covalent bonds into the conduction band.
lue of minority current in silicon roughly doubles for
ery 6° C rise. Even though this is a a more rapid in-
ease than for germanium, the initial value is so low t
licon is generally preferred for high temperature work
100 C.

e breakdown

the reverse voltage across the junction is gradually
creased, a point is reached where the reverse current
arts to increase rapidly. This incease may be exceedi
rupt in silicon junctions. The breakdown characterist
indicated at Vbd (voltage breakdown) in figure 22.
tice that Vbd stays essentially constant for large var
ion in current. This is characteristic of a constant
ltage source and is the basic principle on which the
oltage-regulating" or zener diodes operate.

e sudden increase in current may be the result of eith
two mechanisms. First, if reverse bias is sufficient
creased, it is possible for the electrical field in th
cinity of the junction to b ecome quite strong - so
rong, in fact, that electrons are suddenly pulled out
valent bonds when Vbd is reached. This phenomenon is
own as <u>zener</u> <u>breakdown</u>.

e second and more common type of breakdown, called
<u>alanche</u> <u>breakdown</u>, is due to a secondary emission effe
nority carriers produced by covalent bond breakup, are
celerated across the junction by the reverse bias. Wh
verse bias approaches a critical value, the minority
rriers have sufficient velocity to knock apart covalen
nds of atoms they collide with, and these in turn brea
her bonds, and so forth. The consequence is that a
emendous increase in the number of current carriers
sults which make the semiconductor material and juncti
pear to have a low resistance.

ode reverse current in the breakdown region should be
mited by an external resistance if reverse bias is to
ual Vbd. The diode will not be harmed if the current

likened to the dielectric of a capacitor.
bordering the depletion region have good
because of the presence of charge carrie
be compared to the plates of a capacitor.
of the depletion region is controlled by
the reverse voltage, here is a capacitor
depends upon the junction voltage. The
varies with the method of fabrication of
typical values range from 3 to 100 pF.

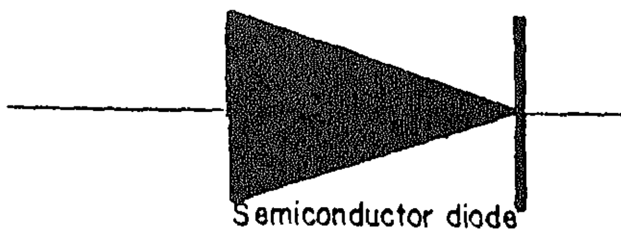
B. In the recent years some manufacturers o
devices have made voltage-sensitive capa
available. They have found extensive ap
electronic equipment, particularly in th
cations, as oscillator frequency control

XII. Diode symbols

A. Some facts hold true of all semiconducto
these are stated here. (Refer to figure

B. Figure 23 shows schematic representation
diode. The arrowhead of the drawing wil
anode. The anode will always be the P-t
cathode will always be the N-type materi

C. In order to forward bias the diode, the
positive with respect to the cathode. T
diode, the anode must be negative with r
cathode.



Semiconductor diode.

Figure 23.

Kiver. Transistor and Integrated Electronics.
NY.: McGraw-Hill Book Company. 1972, Fourth Edition.

and Osterheld. Essentials of Radio-Electronics.
NY.: McGraw-Hill Book Company, Inc., 1961, Second

Metcalf, Lefler, and Williams. Modern Physics.
NY.: Holt, Rinehart, and Winston, Inc., 1968.

LINE:

structure

neral information

e atom

eriodic chart

F. Energy levels of isolated atoms

bands

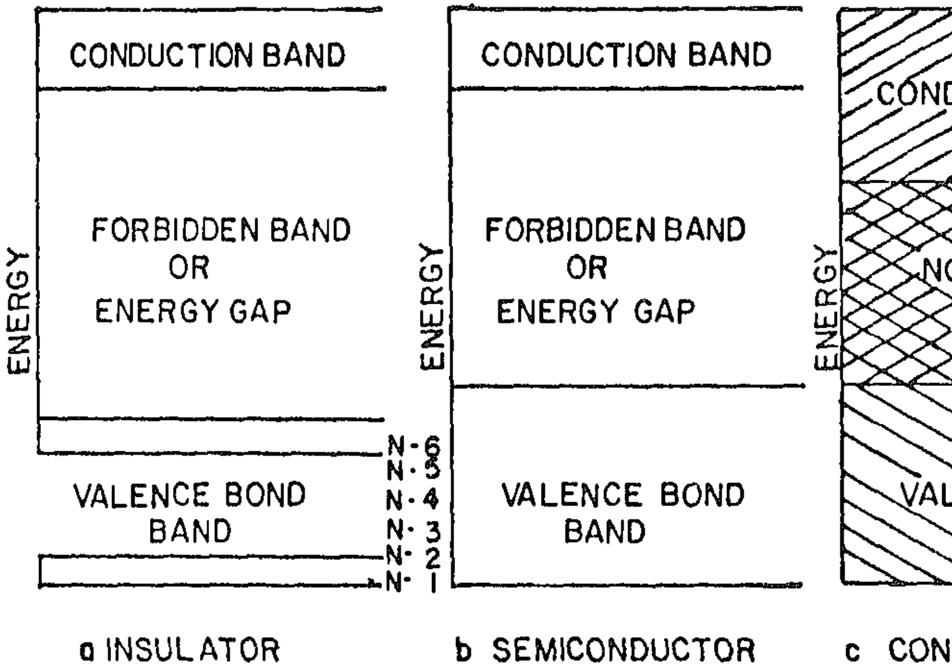
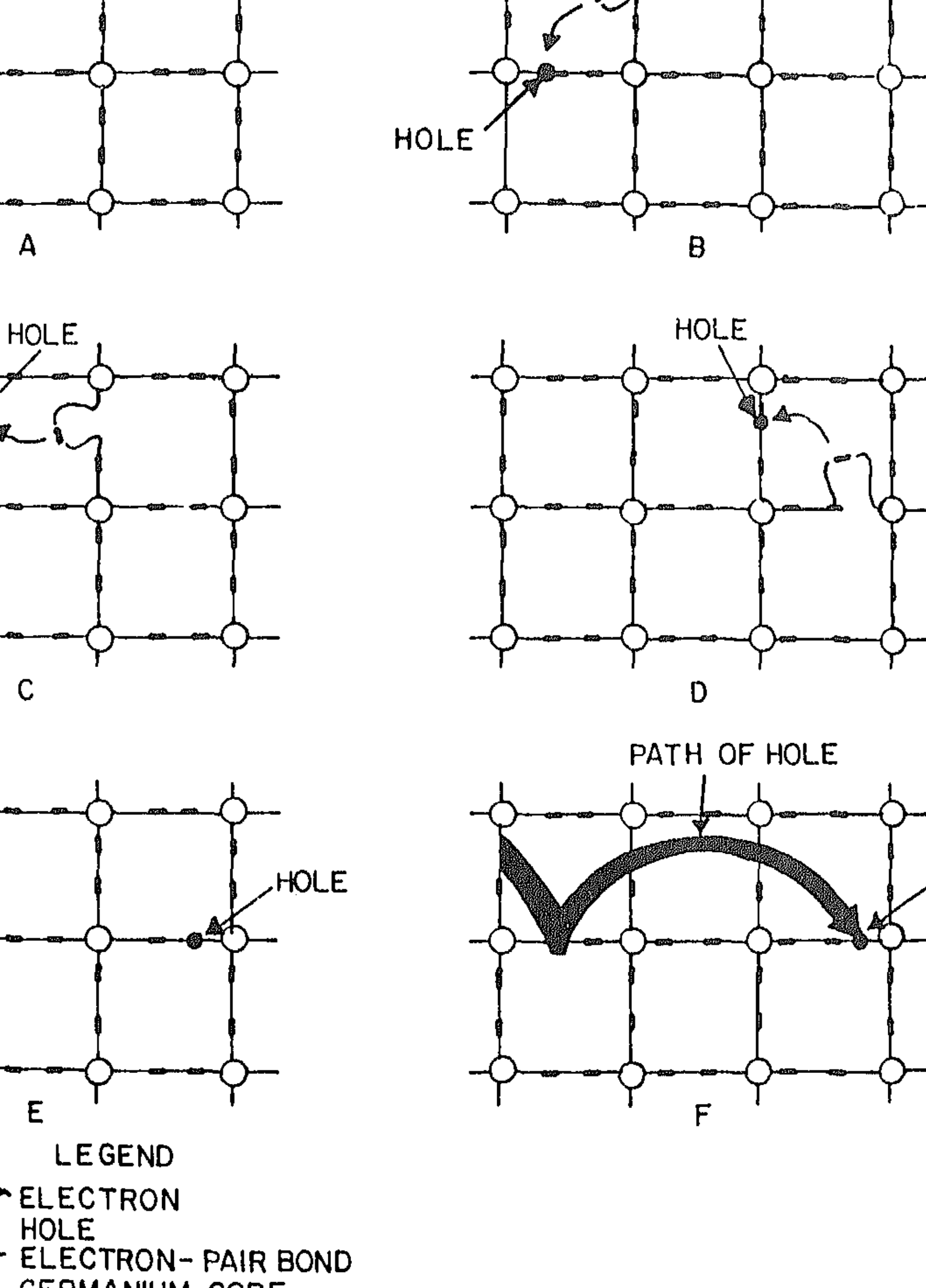


Figure 1. - Energy bands: (a) insualtor (b) semi
(c) conductor

II. Intrinsic materials



HOLE
A
B
HOLE
HOLE
C
D
HOLE
PATH OF HOLE
E
F
LEGEND
ELECTRON
HOLE
ELECTRON- PAIR BOND

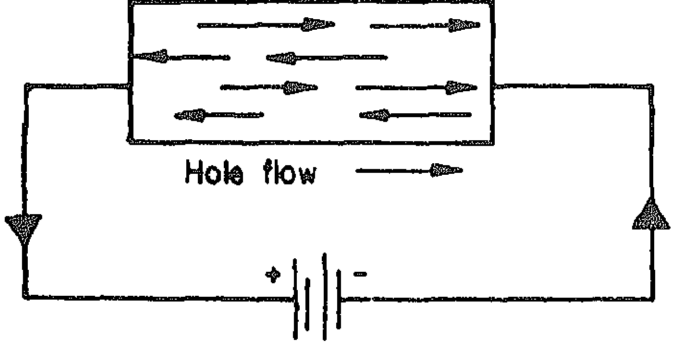
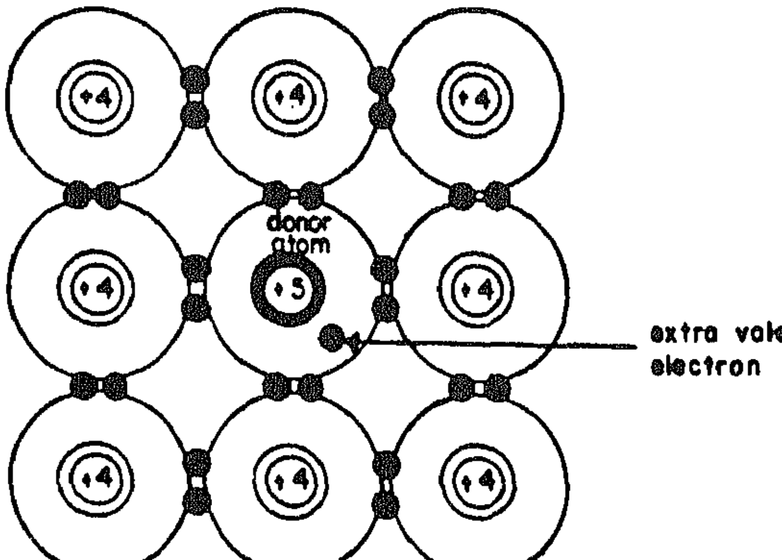


Figure 3.--Intrinsic conduction.

III. Extrinsic materials



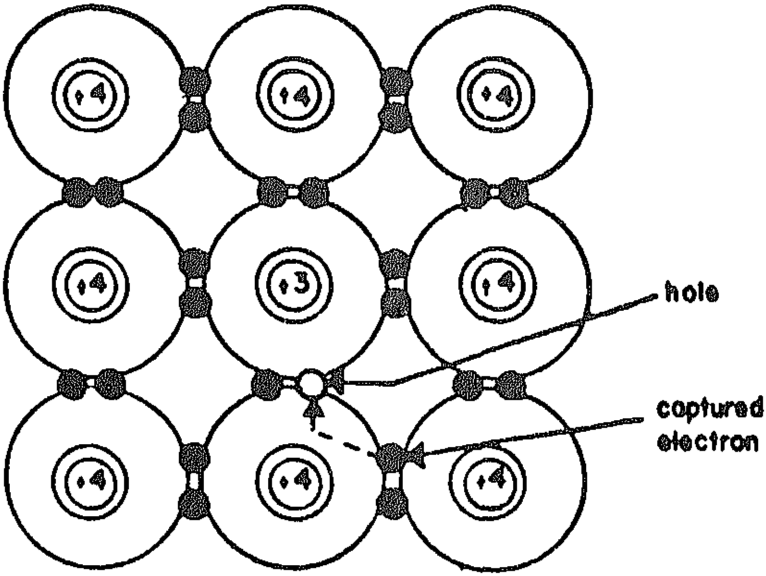


Figure 5.--P-type semiconductor material.

rical properties of semiconductors

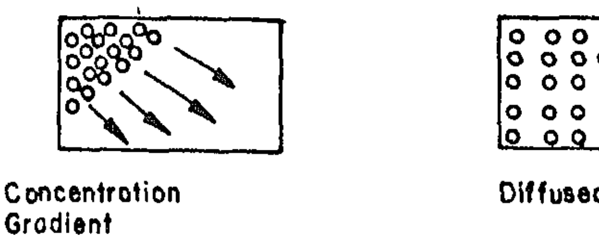
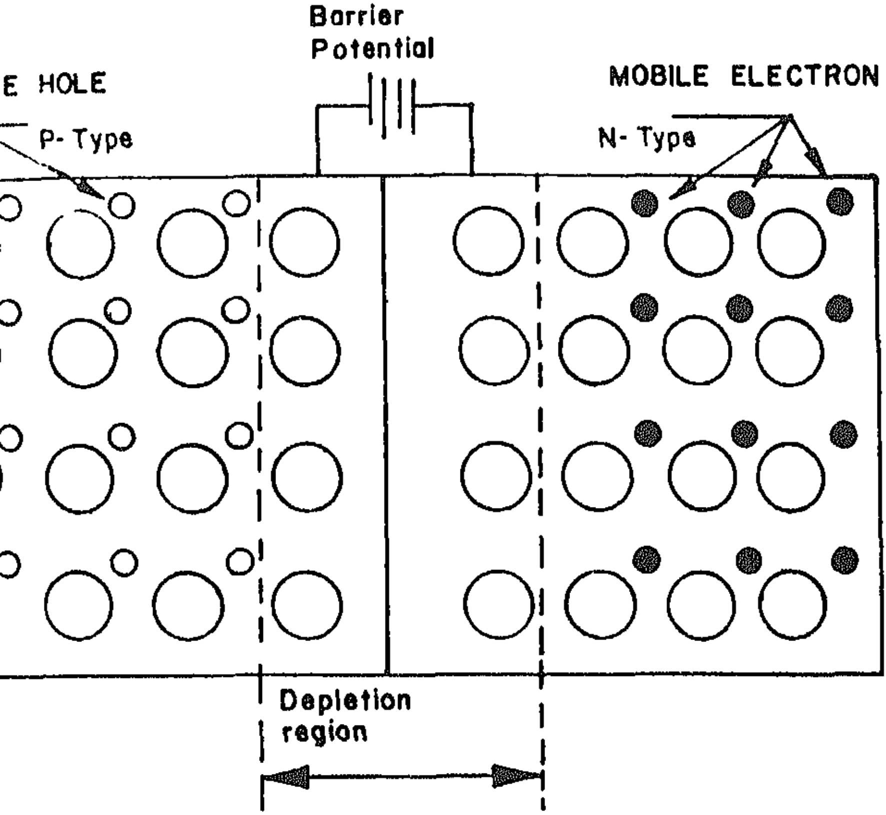


Figure 6.--Diffusion.



gure 7.--Charges in an unbiased PN junction.

rse biased PN junctions

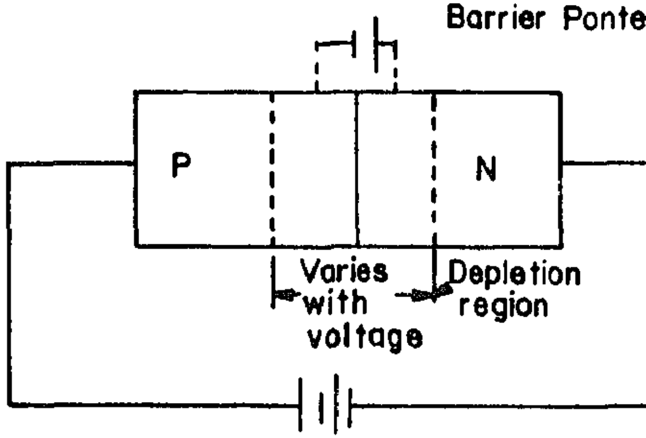


Figure 8.--Forward biased PN juncti

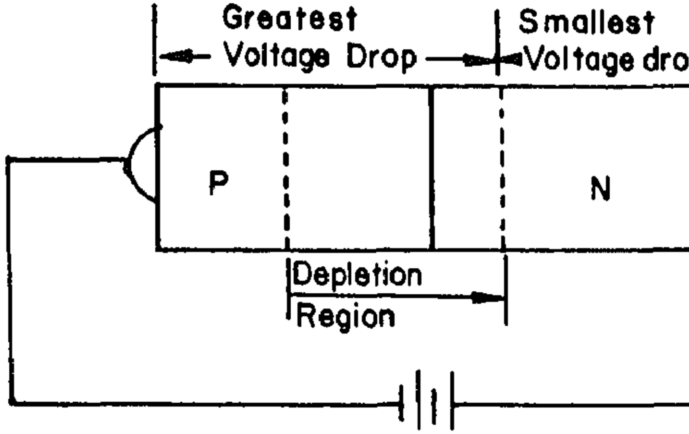
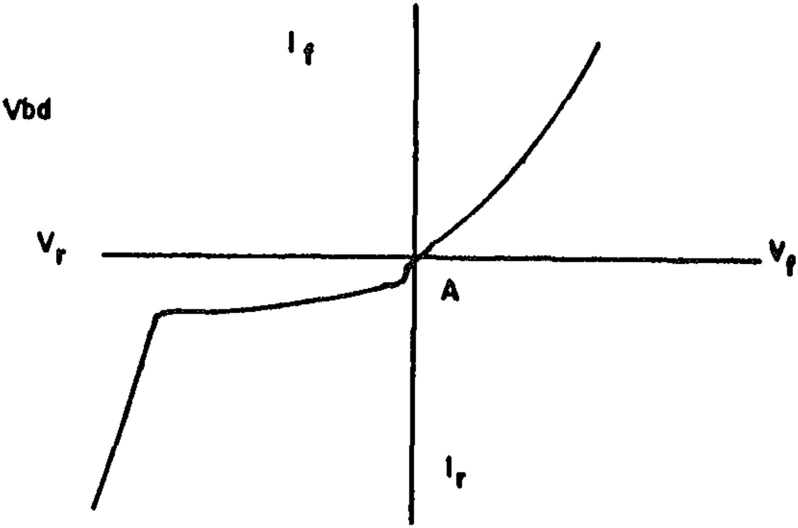


Figure 9.--Reversed bias PN juncti



ure 10.--Reverse bias versus reverse current.

e Symbology and use

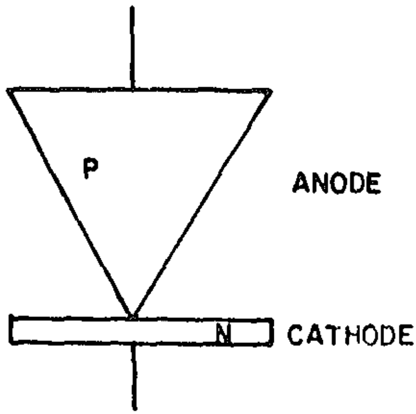


Figure 11. Diode symbology

the data sheet is for you to record the effects of
erse bias on a PN junction and the effects of
nges on current flow through the junction.

d reverse-biased PN junction:

e table 1, entering d-c measurements in spaces
d.

ORWARD BIAS		REVERSE BIAS	
	I_B	$+V_{BE}$	I_B
V	____________	+0.1 V	____________
V	____________	+0.5 V	____________
V	____________	+2.0 V	____________

TABLE 1

e the following graph, using the information obtai
ble 1.

respect to minority current carrier

____

(b) State the effect of removing heat f
tion with respect to minority curre

____

d. PN junction resistance calculations:

(1) Forward-bias resistance at -0.2 V ______

(2) Reverse-bias resistance at +2.0 V ______

e. Questions (Fill in the blanks.)

(1) The major characteristic of a PN juncti
biased is $\underset{\text{low/high resistance}}{\underline{\hspace{6em}}}$.

(2) When reversed-biased, the PN junction r
very $\underset{\text{low/high}}{\underline{\hspace{3em}}}$.

(3) When temperature increases, the amount
current $\underset{\text{increases/decreases}}{\underline{\hspace{6em}}}$.

(4) If not controlled, what effect will a c
in temperature have on the PN junction?

____

____

____

creased utilization of transistors, it has become
hat you as technicians acquire an understanding of
The main purpose of this information sheet is to gi
the fundamental principles of transister action.

ic-Circuits, NAVSHIPS 0967-00-0120, pp. 5-10 to 5-20.

als of Radio-Electronics, Slurzberg & Osterheld, McGra
, 1961 2nd Editioin.

tor and Integrated Electronics, Kiver, McGraw-Hill Co.
Edition.

TION

eral information

The advantages of using transistors are well known an need only cursory mention. Chief among the advantage are the small physical size and the extreme ruggednes the transistor. Although designed to perform many of functions of the vacuum tube, this device requires no filament power and operates with very low bias voltag

Although the disadvantages of the transistor are stea being diminished, present limitations to its use exis There is still a basic limitation on the power handli ability, and the temperature dependence of its charac istics are often a challenge. The low resistance of transistors to radiation fields is another disadvanta

With the increased utilization of transistors, it has become essential that technicians acquire an understanding of transistors. The main purpose of this information sheet is to draw forth the fundamental principles of transistor action.

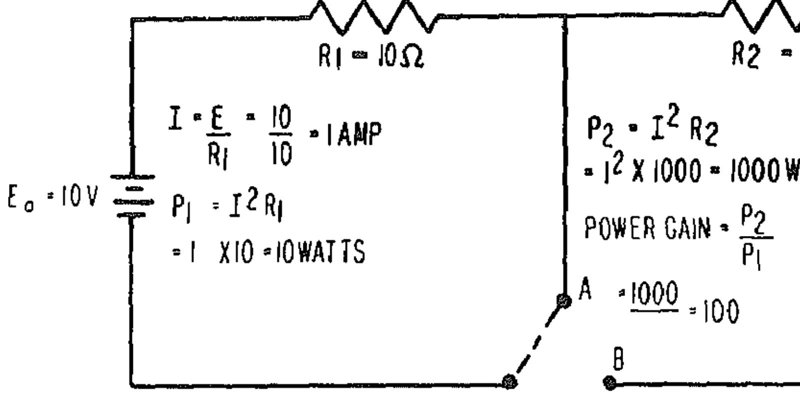


Figure 1 Tran<u>sfer</u> + Res<u>istor</u> = Transistor

Connecting resistor R_1 in series with the l
by placing the switch in position "A" would
ampere of current to flow, resulting in a p
pation in R_1 of 10 watts. If, when throwin
to position "B" approximately the same 1 am
made to flow through R_2, a hundredfold gain
dissipation would result. If R_2 were in a
offer a large portion of the dissipated pow
external load where useful work could be pe
figure 1 could be considered an active circ
its ability to amplify power. The transfer
across two resistance ratios gives rise to
transistor, and is the basic analogy of tra
action.

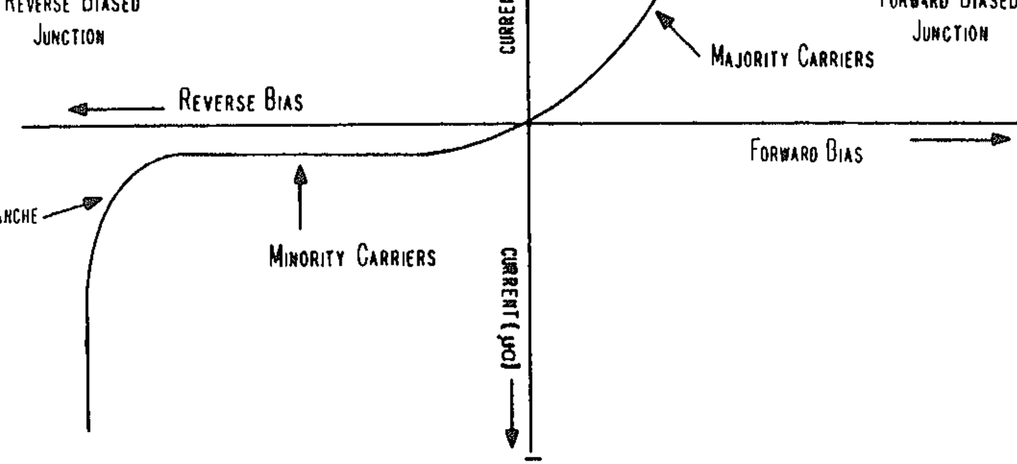
2. It is suggested that the reader review figu
operation before continuing, and keep in mi
the analysis of transistor action that in i
form transistor action consists of:

   a. Transferring approximately the same cur
   unequal resistances.

   b. Utilizing the power developed across th
   resistance to perform some useful work.

C. Transistor analysis

   1. In your previous lesson on junction diodes,



Conditions existing at a forward and reverse-biased PN junction.

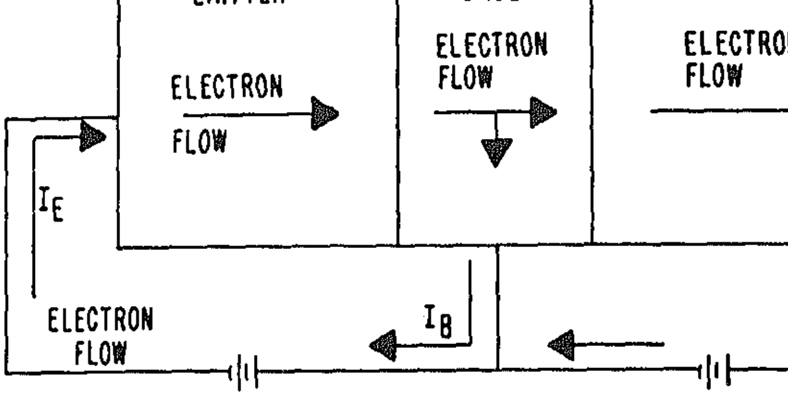
Further observation of figure 2 reveals that the PN junction biased in the reverse direction is equivalent a high resistance element (low current for a given voltage). Notice also that as the reverse bias voltage increases, the minority current remains relatively constant until avalanche is reached. Thus, it can be seen in figure 2 that:

a. The amount of current flow through a forward-biased junction is primarily voltage dependent.

b. The amount of current flow through a reverse-biased junction is not voltage dependent, but primarily dependent upon the number of minority carriers in P-and N-type materials.

Applied logic at this time will reveal the transistor action idea.

If a crystal containing two PN junctions were prepared, signal could be introduced into one PN junction biased the forward direction (low resistance) and extracted the other PN junction biased in the reverse direction (high resistance). Such a device would transfer the signal current from a low resistance to a high resist circuit.



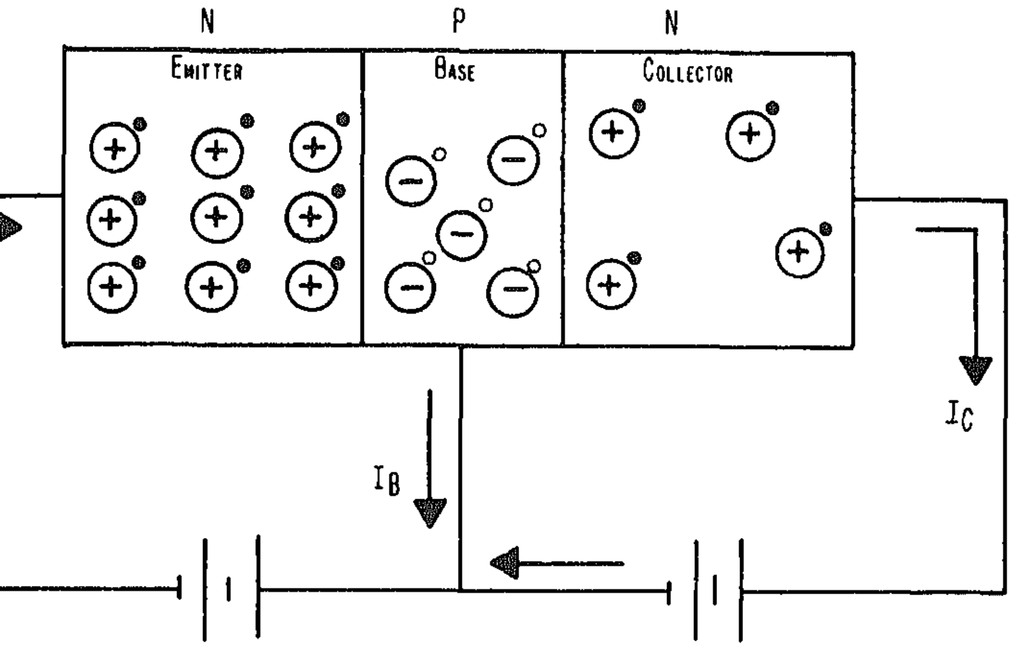
NPN Transistor

Figure 3

3. Figure 3 depicts the basic model of trans
Notice that the N-type material labeled em
biased with respect to the P-type base, an
collector is reverse biased with respect
base. Resistors R_1 and R_2 represent the
emitter-base junction and collector-base
respectively.

4. A basic analysis is as follows: with the
junction forward biased a current will flo
junction. Some of this current will conti
P-type base, and some will exit the P-type
forward-biased battery. In figure 2, it
that current flow across a PN junction und
biased conditions is due to minority carr
model, the electrons in the P-type base w
carriers. It was also stated that the cu
reverse-biased junction was dependent upo
minority carriers and not the bias voltag
some percentage of the original carriers
crossed the base-emitter junction could c
collector-base junction. Because the col
junction is reverse biased, it offers a h
the electrons which cross the junction (r
resistor R2). Thus, we have transferred
low resistance to a high resistance.

he high resistance. Thus, our problem is to minimize
urrent flow out of the base lead in figure 3, and to
ause most of the current that crosses the emitter-base
unction to cross the collector-base junction as well.



zed Donor Atom o Mobile Free Hole

zed Acceptor Atom · Mobile Free Electronc

hanges in the Emitter, Base, and Collector Region

Figure 4

igure 4 shows a schematic illustration of the charge
istribution in the emitter, base, and collector region
transistor. The valence 4 atoms; i.e., silicon or
ermanium, are not shown and should be imagined as a
ontinuous crystal structure over the whole background

otice that there are more carriers in the N-type emitt
han in the P-type base, and that there are more carrie
n the base than in the N-type collector (as a result

concentration of electrons and so will ver
recombine in the N-type region.

9. Re-examination of figure 4 will show that
which enter the P-type base region must tr
into the region itself in order to recombi
The electrons in the base region are in ef
spread themselves out in order to recombin
was defined in your lesson on PN junctions

10. Each time an electron does recombine with
P-type base region, the region is no longe
neutral, but takes on a negative charge (r
atom that takes on an excess electron is d
negative ion).

11. In order to regain its electrical balance,
give up an electron to the external circui
rise to a current called I_B (base current)

12. Again recall that our goal is to get as mu
of our emitter current (I_E) to flow throug
region and become collector current (I_C).
figure 1.) Figure 3 reveals that collecto
is simply the emitter current (I_E) minus a
(I_B).

$$I_C = I_E - I_B$$

Therefore, minimizing I_B will cause I_C to

13. The action taken to minimize I_B should be
understood at this time. As stated earlie
electrons must travel by diffusion through
region. The distance they travel through
(base) region before they recombine with a
their diffusion length. Now, let us intro
junction by arranging a second N-type mate
to the right of the base and, at the same
base itself very thin. As the electrons d
the center P-type (base) region, some of t
the process. However, if the width of the
very small as compared to the diffusion le
electrons only a few recombinations will h

tor base junction are electrons in the P-type base
al (minority carriers). Therefore, the collector-
unction will appear as a forward bias, and the
ons will be swept across the junction. These excess
ons in the N-type collector will give it an excess
ve charge which it can easily give up to the
al battery terminal in the form of I_C. Recall also
t is not the reverse bias voltage that is con-
ng the amount of electrons, but the forward biased
r-base junction which controlled the electrons
g into the base.

ocess of causing majority carriers to cross over a
ction and flow as minority carriers on the other
s called injection. This process describes precisely
tion that takes place at the emitter-base junction.

cture on transistor action is now complete, and can
cribed as three basic mechanisms:

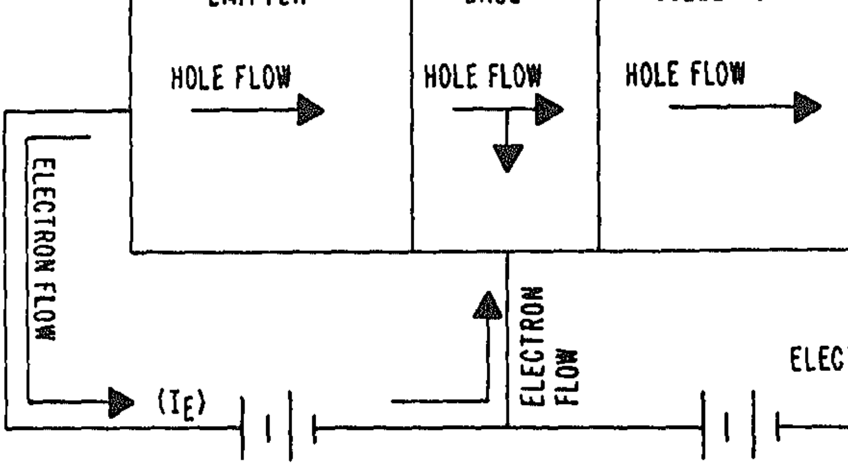
jection - The process (under forwrd bias conditions)
ere majority carriers from the emitter are made to
oss the emitter-base junction and flow as minority
rriers in the base region.

ffusion - The process by which the minority carriers
lectrons) in the P-type base region travel (from an
ea of high carrier concentration to an area of low
rrier concentration).

llection - The process of causing minority carriers
lectrons in a P-type material) to become majority
rriers (electrons in an N-type material) and giving
em up to the external circuit.

transistor model, external current was supported by
ty carriers (electrons) in the transistor itself.
ectrons are majority carriers in both the emitter
llector, both of which are N-type carriers. The
hree mechanisms of transistor action can be achieved
NP transistor.

5 depicts the basic model of a
that in this configuratio
tor are both P-type materi



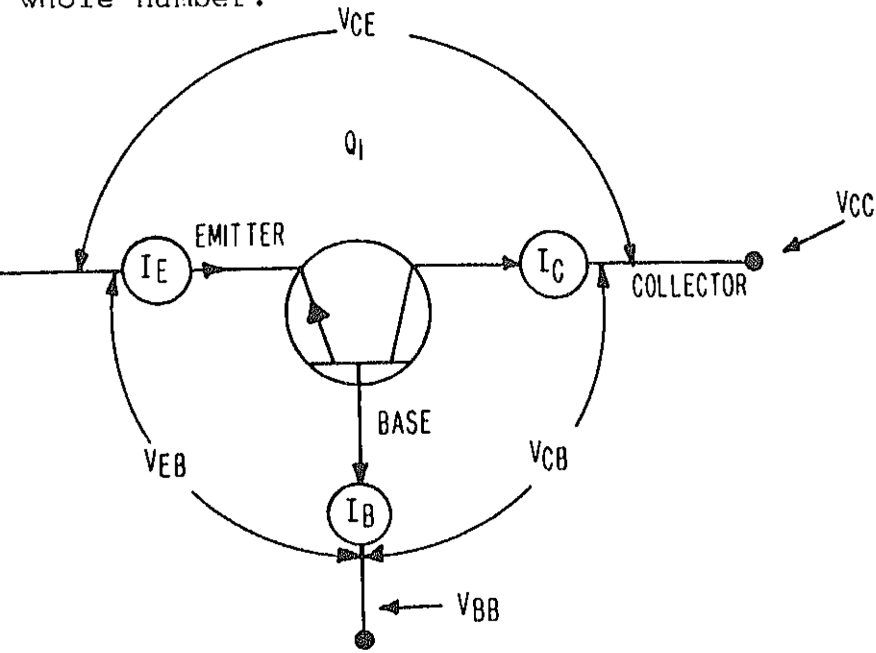
PNP Transistor

Figure 5

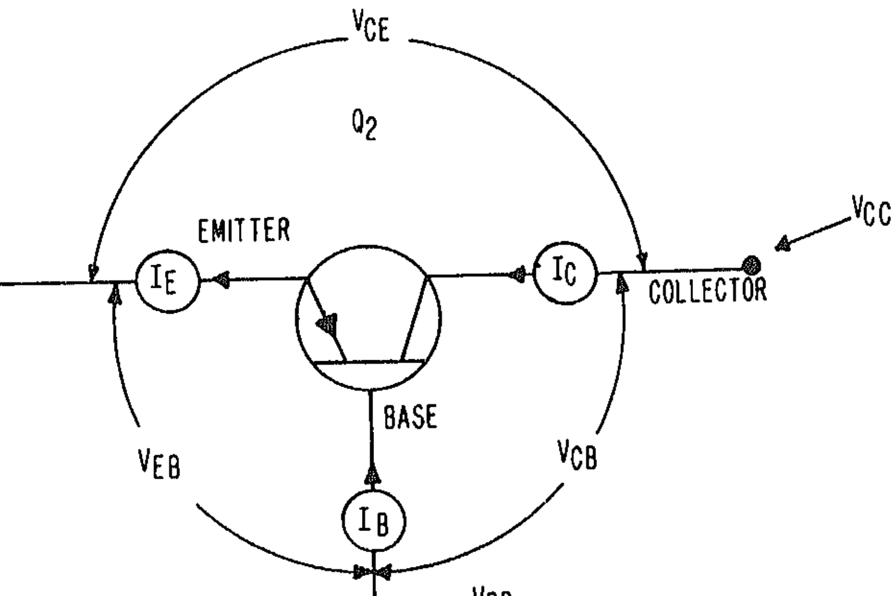
19. As forward bias is applied to the emitte holes are accelerated across the emitter- Once the holes enter the base region, the carriers (holes in an N-type material). recombine with some of the excess electr base, creating positive ions. In order electrical balance, the base will readil electron from the external circuit for e which is created by an electron-hole rec However, in order to reduce the number o in the base, the base is made very thin more heavily doped just as in the case o transistor (figure 4). The holes that d the base region continue to travel by th process; i.e., from an area of high carr to an area of lower carrier concentratio which diffuse near the reverse-biased co junction are swept across the junction b electric field. Once these holes enter collector region, the collector must acc the external circuit in order to achieve balance.

20. Thus, the external circuit current (elec supported by internal majority current c

ference designations and schematic symbols for stors are shown in figure 6 (A) and (B). The letter n of the reference designation is Q. The number may whole number.



ransistor



2. In the PNP transistor (B, figure 6), the
to-collector current carrier in the devic
For holes to flow internally from emitter
the collector must be negative with respe
emitter. In the external circuit, electr
collector to emitter opposite to the dire
emitter arrow.

3. The following generalizations are helpful
behavior of transistor circuitry. These
apply to a transistor that is operated as
amplifier.

   a. The first letter of the type of trans
   the polarity of the emitter voltage w
   the base. A PNP transistor has posit
   applied to the emitter ($+V_{EE}$). A NPN
   negative voltage applied to the emitt

   b. The second letter of the type of tran
   the polarity of the collector with re
   base. A PNP transistor has negative
   applied to the collector ($-V_{CC}$). An
   has positive d-c voltage applied to t
   ($+V_{CC}$).

   c. The first and second letter of the ty
   indicate the relative polarities betw
   and the collector respectively. In a
   the emitter is positive with respect
   the collector is negative with respec
   ($-V_{CE}$). In an NPN transistor, the em
   with respect to the collector; the co
   positive with respect to the emitter

   d. The d-c electron current direction is
   the direction of the arrow on the emi

   e. If the electrons flow into or out of
   electrons flow out of or into the col
   respectively (I_C).

   f. The base current is always equal to t
   current minus the collector current (

egative with respect to the base ($-V_{CB}$). In an NPN
ransistor, the collector is positive with respect to
he base ($+V_{CB}$).

n input voltage that aids (increases) the forward
ias increases the emitter and collector currents.

n input voltage that opposes (decreases) the forward
ias decreases the emitter and collector currents.

he reverse bias voltage (V_{CB}) is normally much
reater than the forward bias voltage (V_{BE}) in a
ransistor. Typical values of V_{CB} range from 3 to 8
olts d-c. Typical values of V_{BE} are .2 volts d-c for
ermanium and .6 volts d-c for silicon crystals.

gurations

transistor is a three-element, three lead device,
sible to use it in any of three different, useful
tions. The identification of each of these
l circuits is derived from the element "common" to
t and output. The three possible connections are:
se, common-emitter, and common-collector. An often
ation is "grounded' emitter, "grounded" base, etc.,
common element is usually returned to the signal
int in a circuit.

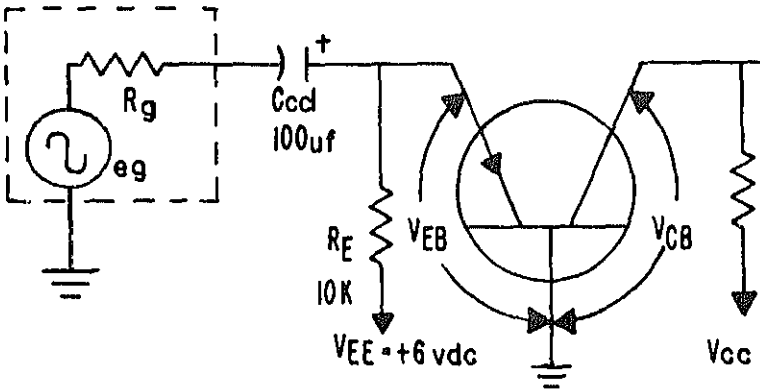
se amplifier

convenient to start a detailed examination with the
n-base amplifier, which is normally considered to be
reference amplifier" for any comparisons of the three
fier configurations.

e 7 is a schematic drawing of a common-base amplifier
e PNP type. Notice that the input is supplied
en the emitter and base. Thus, the base is common to
the input and output. In "transistor symbology" you
given some general rules to follow when analyzing
istor circuits. Following these rules,
roper operation that V_{EE} must be a posi
$_{CC}$ a negative voltage for proper bias p

source, and R_C is chosen to provide the d
gain. The reverse-bias voltage (V_{CB}) is
$I_C R_C$. The reverse bias voltage will norma
(3 to 6 volts) as comapred to the forward

4. Let us analyze the amplifier under dynami
conditions.



Common-Base Amplifier

Figure 7

currents. The decreasing collector current will
voltage drop across R_C, making the collector more negative. ($V_{CB} = V_{CC} - I_C R_C$). Thus, a oing input signal produces a negative-going nal. During the positive half-cycle of the al, the emitter will be driven more positive s under static (no signal) conditions. This ase the current in the emitter and collector cause the voltage drop across R_C to increase. see that the polarity of the input signal the polarity of the output signal.

tput, a load resistor (R_C of 1000 ohms) is used. the current is concerned, there is less at the e., collector) than at the emitter. $I_C = I_E$ ifference (I_B) is normally 1 or 2 percent of the ent in the device (I_E).

of the change in the output current (I_C) to the

the input current (I_E), or $\frac{I_C}{I_E}$, is referred to

pha" (∂) of the transistor. Thus, the current is amplifier arrangement is less than 1, and lead one to believe that the circuit has little is not true; a large voltage gain may be because the output load resistance is much an the input resistance. Thus, if we assume an stance of 50 ohms (the forward biased emitter-ion) and utilize a 1000 ohm load resistance, the in (input to output) is:

$$\text{in} = \frac{\Delta E_{out}}{\Delta E_{in}} = \frac{\Delta I_C R_C}{\Delta I_E R_{in}}$$

0.98 for a typical value

$$\text{in} = \frac{\Delta E_{out}}{\Delta E_{in}} = 0.98 \times \frac{1000}{50}$$

$$= \frac{\Delta I_C{}^2 R_C}{\Delta I_e{}^2 R_{in}}$$

$$= .98^2 \times 20$$

$$= .96 \times 20$$

Power gain = 19.2

8. In the input impedance of a transistor in th configuration is very low because of the for emitter-base junction. The output impedance the load resistor and look into the collecto high, on the order of 1 to 2 megohms. Howev connect a load resistor of 1000 ohms, then t value of the output impedance since it compl the 1 to 2 megohms with which it is basicall It is well for the reader to keep this disti because reference is often made in literatur output impedance of the common-base arrangem means without the load resistor. Once a muc resistance is connected to the collector, it essentially determine the output impedance.

9. In summary, the characteristics of the commo amplifier configuration are:

   a. No phase inversion between input and out

   b. Low input resistance because of forward (V_{EB}) typical values 50-100 ohms.

   c. The output signal sees a reverse biased

      (1) Typical values 1-2 megohms.

      (2) In a practical circuit, R_C shunts th resistance of the transistor.

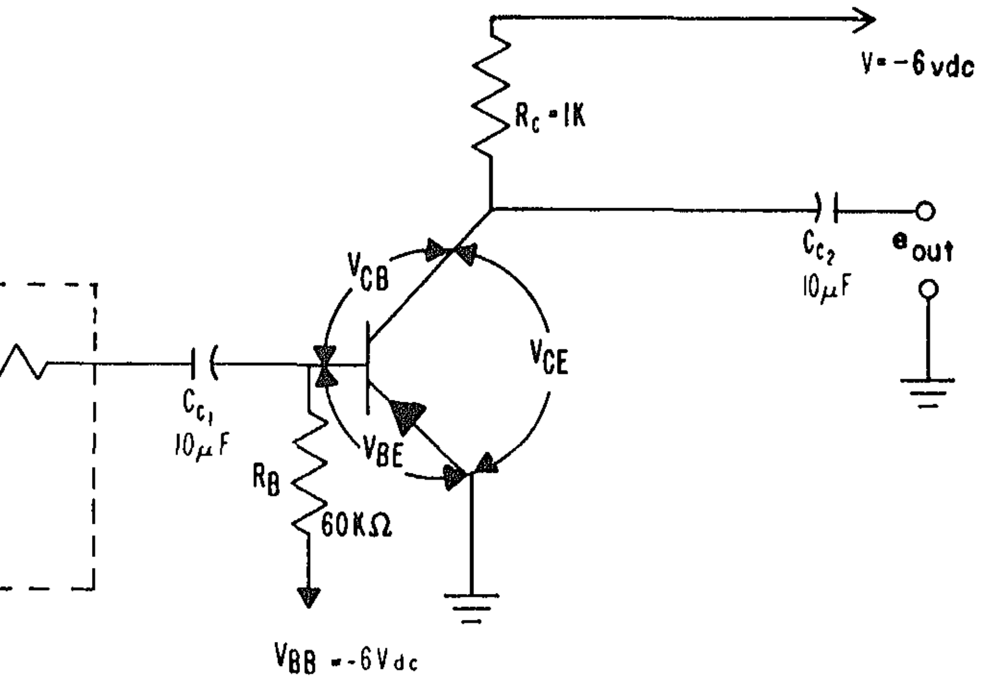
   d. The output to input resistance ratio is leads to a very high voltage gain.

e input signal is applied between the emitter and the
se.

e output signal is taken between the collector and
e base.

e base is "common" to both the input and the output.

tter amplifier



Common-Emitter Amplifier

Figure 8

volts (V_{BB}). Current flow through the base ... the base resistor R_B, a 60 k-ohm resistor. ... I_B (approximately equal to $\frac{V_{BB}}{R_B}$) will develo...

forward bias voltage across the base emitte... (V_{BE}).

2. As is normally the case, this forward bias ... very small. V_{CC} is the collector supply so... chosen to provide the desired voltage gain ... bias voltage (V_{CB}) is equal to V_{CC} $-I_CR_C$ -V...

3. Again, let us analyze the amplifier under ... ditions. As the incoming signal goes negat... aid (increase) the normal negative bias bet... emitter (V_{BE}). An input voltage that aids ... will increase the emitter and collector cur... increasing collector current will increase ... across R_C, making the collector potential ... positive ($V_C = V_{CC} - I_CR_C$). Thus, a negati... signal produces a positive-going output sig... positive half-cycle of the input signal, th... driven more positive than it was under sta... conditions. This will decrease the curren... emitter and collector leads causing the vo... R_C to decrease. This decreased voltage dr... to become more negative. Thus, in the comm... amplifier polarity inversion between input...

4. For the output, a load resistor of 1000 oh... utilized to compare the characteristics of ... those of the common-base amplifier.

5. Since the input signal is applied to the ba... common-emitter amplifier, it is the variat... signals on the base which control the coll... As stated previously, $I_C = I_E - I_B$. It was ... the difference in I_E and I_C is I_B, which i... percent of the total current (I_E). In fact ... was intentionally designed to minimize I_B; ... region, heavily doped emitter. Thus, it f... minute variations of base current produce ... variations in collector current. If we as...

current gain in the common-emitter amplifier is

$$t \text{ gain} = \frac{\Delta I_C}{\Delta I_B}$$

f $\frac{\Delta I_C}{\Delta I_B}$ is called Beta (β). In our amplifier the

t would be .1 mA, while the collector received
ostituting these values, we obtain

$$\frac{\text{ma}}{\text{ma}}$$

sizeable current gain is obtained, in contrast
l loss incurred in the common-base amplifier.
esistance of the common-emitter amplifier is
higher than the input resistance of the
amplifier. As was the case with the
amplifier, the input is applied across a
sed junction (V_{EE}); however, the current flow
junction (I_B) is quite small as compared to the
w through the common-base forward-biased

$$\frac{V_{BE}}{I_B}$$

$$\text{values} = \frac{.2 \text{ volts}}{.1 \text{ mA}} = 2 \text{ k-ohms}$$

impedance, looking into the collector, before
connected, is about 500,000 ohms. This is
ss than the value presented by the common-base

$$\frac{\quad}{\Delta I_B} \times \frac{\quad}{R_{in}}$$

$$= 49 \times \frac{1000}{2000}$$

$$= 24.5$$

8. This is somewhat larger than the voltage gain the common-base amplifier. The difference is much; however, power gain is considerably bett

$$\text{Power gain} = \frac{\Delta I_C{}^2 R_L}{\Delta I_B{}^2 R_{in}}$$

$$= 49^2 \times .5$$

$$= 1200.5$$

9. In summary, the characteristics of the common- amplifier are:

   a. There is a polarity inversion between the output.

   b. Higher input resistance than the CB amplif value 2 k-ohms.

   c. The output resistance of the common-emitte less than that of the common-base amplifie R_C will shunt the output just as it did th amplifier.

   d. The output to input resistance ratio is mo leads to a good voltage gain.

   e. There is a good current gain in the commor configuration.

$$\frac{\Delta I_C}{\Delta I_B} = \beta$$

(b) $I_B = I_E - I_C$

(c) $\beta = \dfrac{I_C}{I_E - I_C}$

(2) Dividing denominator and numerator by I_E

$$\frac{\frac{I_C}{I_E}}{\frac{I_E}{I_E} - \frac{I_C}{I_E}}$$

(3) However, $\dfrac{\Delta I_C}{\Delta I_E} = \alpha$

By substitution; $\beta = \dfrac{\alpha}{1 - \alpha}$

(1) It can be seen that by keeping the recombination currents in the base circuit very low, alpha approaches unity.

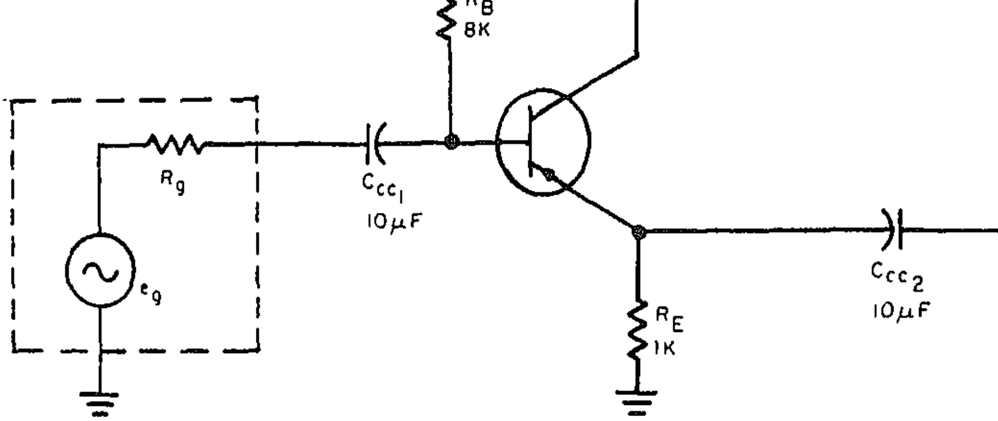
(2) As α approaches unity, β will approach infinity.

There is a very high power gain in the common-emitter amplifier.

is because of its higher current gains, power gains, a relatively close input-to-output impedance ratio (1 t n our example), that the common-emitter amplifier con- uration is the most popular configuration in transisto cuits.

Collector Amplifier

final transistor amplifier circuit arrangement is the mon-collector. This is shown schematically in figure e that the collector of the transistor is not at d-c und since the collector still requires a $-V_{CC}$. Note al bias polarities. They are the same polarities as wer uired for the common-emitter amplifier in figure 8.



Common-Collector Amplifier

Figure 9

2. The input signal will be developed across the base collector junction (the collector is the common el and the output signal will be developed across the resistor R_E. Thus, in the common-collector amplifi input is applied to the base and the output is tak the emitter with the collector the common element.

3. Analyzing the amplifier under dynamic conditions, incoming signal goes negative, it will aid the nor negative bias between base and emitter (V_{BE}). An i aids forward bias will increase the emitter and co currents.

4. The increasing emitter current will increase the v drop across the emitter resistor R_E (negative to p from the top of R_E). Therefore, a negative-going i signal will develop a negative-going output signal the positive half-cycle of the input signal, the b be driven more positive than it was with no signal This will decrease forward bias, and will lend to decreasing current in the collector and emitter le decreased emitter current will decrease the voltag across the emitter resistor, causing the output si go in the positive direction, Thus, in the common- configuration, there is no polarity inversion betw and output. The current gain of a common-collecto

$$= \frac{I_C}{I_B} + \frac{I_B}{I_B}$$

$$= \beta + 1$$

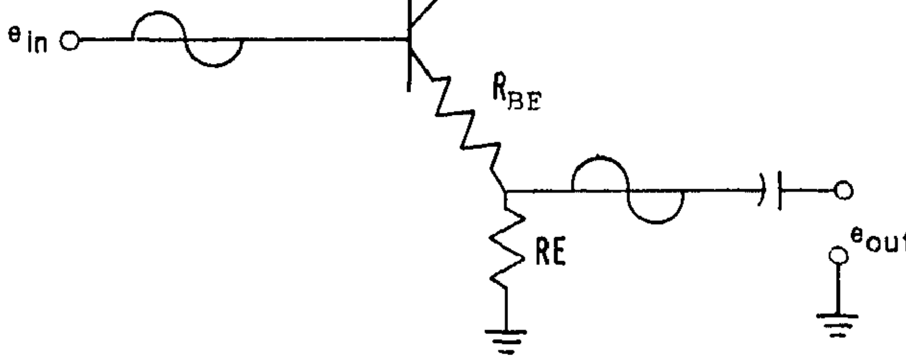
of the change in output current, I_E, to the

rent, I_B, or $\frac{\Delta I_E}{\Delta I_B}$ is referred to as "gamma", γ.

ge gain of the amplifier is always less than 1, generally it is not much less than 1. The emitter develops the output signal which will be in the rity as the input.

seen in figure 10, as the input signal goes (which would increase forward bias), the output also goes negative, which tries to reduce the ias. The actual difference between the input and t would be the voltage dropped across the forward tion R_{BE}.

s resistance is very low, the output voltage will ual the input voltage. In short, what we have is ble degeneration.



Input Resistance of the Common-Collector Amplifie

Figure 10

8. Power gain is achieved in the stage because of
current gain, but the gain is less than it is i
common-base or common-emitter characteristics.

9. In summary, the characteristics of the common-c
amplifier are:

a. There is no polarity inversion between the
the output. For this reason the common-col
amplifier is frequently referred to as an
emitter-follower.

b. Highest input resistance of the three possi
configurations. The input is applied betwe
collector-base junction which is reverse bi

c. The output resistance is very low in the co
collector configuration, the emitter resist
primarily the load.

d. The voltage gain is less than 1. You may b
Why use a common-collector stage if the vol
less than unity? Because the input resista
high (approximately 100 k-ohms) and the out
tance quite low (approximately the size of
use the common-collector similar to a trans
that it can be used to transform (step down

e. There is a high current gain in the common-colle
configuration

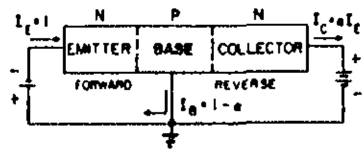
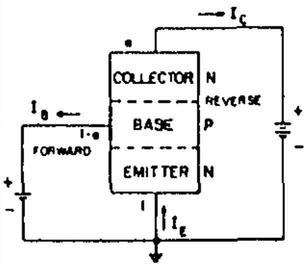
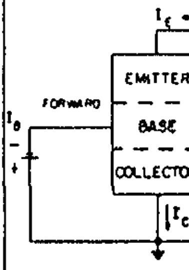
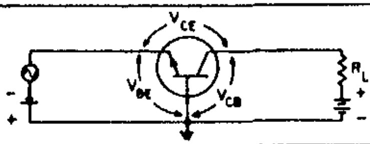
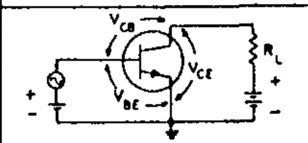
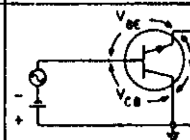
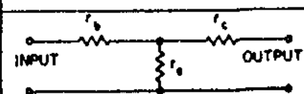
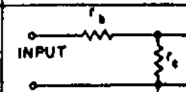
$$\frac{\Delta I_E}{\Delta I_B} = \text{Gamma} = \gamma = (\beta + 1)$$

f. There is a very low power gain in the common-col
amplifier because of the low voltage gain, and l
output resistance.

$$P = \frac{E^2}{R}$$

mparisons of amplifier configurations

Figure 11 is a table of comparisons of the three amp
configurations. Note that there are no comparative
given for current gains, voltage gains, or power gai
The reason is quite simple. The actual values of ci
gains (current, voltage, and power) are dependent on
size of the load and the input resistance.

	COMMON BASE (CB)	COMMON EMITTER (CE)	COMMON COLLEC
SISTOR DEVICE NDICATE N CURRENT ADS NOT	 $h_{FB} = I_C/I_E$ $I_C = I_E - I_B$	 $h_{FE} = \beta = I_C/I_B$ $I_C = I_E - I_B$	 $h_{FC} = I_E/$
ANSISTOR CUITS IGNAL D LOAD (R_L)			
AIN *	YES	YES (HIGHEST)	YES
GAIN *	YES (APPROX. SAME CE)	YES	NO (LESS THAN
GAIN *	NO (LESS THAN UNITY)	YES	YES
PEDANCE *	LOWEST (≈ 50 Ω)	INTERMEDIATE (≈ 1.0K)	HIGHEST (≈ 300
MPEDANCE *	HIGHEST (≈ 1.0 MEG.)	INTERMEDIATE (≈ 50K)	LOWEST (≈ 300
NVERSION	NO	YES	NO
-EQUIVALENT F TRANSISTOR			

operation, or service of electronic equipment is t
transistor manual. Here, we find the mechanical a
electrical specifications for each type of transis
similar fashion, equivalent data is published by t
manufacturers for each of their products. Transis
manufacturers' sheets contain the specifications o
particular transistor, including maximum ratings,
characteristic curves, and physical outline.

1. A typical specification sheet is shown in figu
13. The various sections of the specification
numbered 1 to 3, and the appropriate explanati
will be discussed.

2. We will not cover each specification at this t
the degree of knowledge on transistors require
in later lessons, as your knowledge of transis
increases, you will be able to interpret all o
given by the manufacturer in his specification

   a. The lead paragraph is a general descriptio
   device and usually contains three specific
   information: in this instance, an alloy-j
   germanium PNP transistor, a few major appl
   computers and switching applications, and
   features such as standard size and type pa

   b. The absolute maximum ratings which must no
   exceeded. To exceed them may cause device
   The dissipation of a transistor is general
   by the junction temperature (Tj). Therefo
   higher the temperature of the air surround
   transistor (T_A = ambient temperature), the
   the device dissipates. A factor which ind
   much the transistor must be derated for ea
   increase in ambient temperature is usually
   Note that the 2N404 (given on the specific
   sheet) can dissipate 150 mW at a T_A of 25°
   applying the given derating factor of 2.5
   degree increase in ambient temperature, we
   the power dissipation will drop to zero mW
   This, then, is the maximum operating tempe
   the transistor.

$$\frac{\Delta I_C}{\Delta I_B} = 135.$$

Close parameter control and the JEDEC TO-5 welded package ensure device reliability and stable characteristics

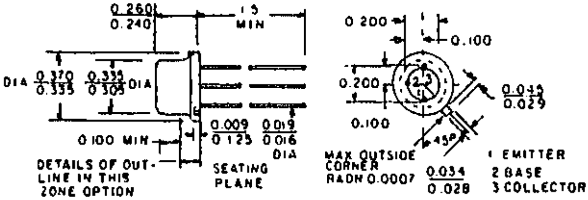
...ental tests

To ensure maximum reliability, stability, and long life, all units are aged at 100°C for 100 hours mi... prior to electrical characterization. All transistors are thoroughly tested for complete adherence to s... design characteristics. In addition, continuous qualification tests are made comprising temper... humidity cycling, shock and vacuum leak testing under rigid in-process control procedures.

...nical data

Metal case with glass-to-metal hermetic seal between case and leads. Unit weight is approximately ... These units meet JEDEC TO-5 registration.

All leads insulated from the case.



ALL DIMENSIONS IN INCHES

...te maximum ratings at 25° C free-air temperature (unless otherwise noted)

	2N404	2N40...
Collector-Base Voltage	25v	40v
Collector-Emitter Voltage (see note 1)	24v	35v
Emitter-Base Voltage	12 v	25v
Collector Current	100ma	150m...
Emitter Current	100ma	150m...
Total Device Dissipation (see note 2)	150mw	150m...
Operating Collector Junction Temperature	85°C	100°...
Storage Temperature Range	-65°C to +100°C	-65°C... +100...

NOTES: 1 Punch through voltage

2. For 2N404 derate linearly to 85°C free-air temperature at the rate of 2.5 mw/°C

For 2N404A derate linearly to 100°C free-air temperature at the rate of 2.0 mw/°C

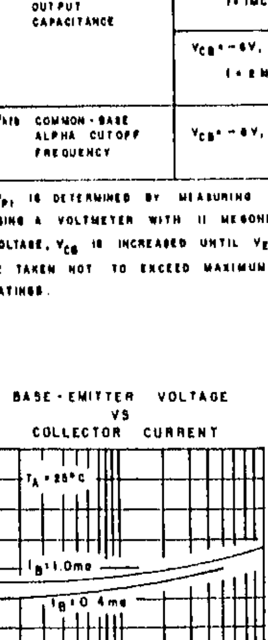
* indicates JEDEC registered data.

The maximum power dissipation at 25°C case temperature is 300mw.

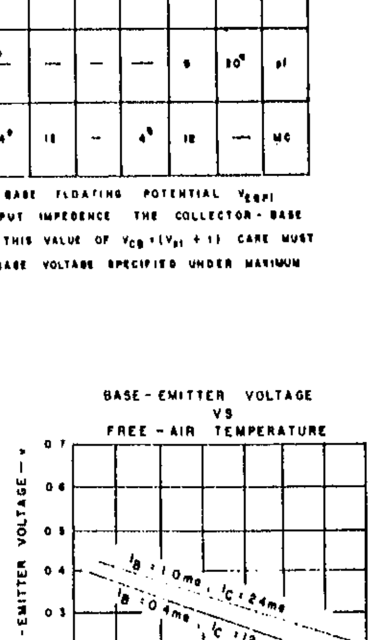
	CURRENT	V_{CB} ... $I_E=0$, $T_A=80°C$	—	-40	-80*	—	-40	-80*	µA
I_{EBO}	EMITTER CUTOFF CURRENT	$V_{EB}=-2.5V, I_C=0$	—	-1	-2.5*	—	-1	-2.5*	µA
V_{CBO}	COLLECTOR - BASE BREAKDOWN VOLTAGE	$I_C=-20µA, I_E=0$	-25*	—	—	-40*	—	—	V
V_{EBO}	EMITTER - BASE BREAKDOWN VOLTAGE	$I_E=-20µA, I_C=0$	-12*	—	—	-25*	—	—	V
h_{FE}	DC FORWARD CURRENT TRANSFER RATIO	$V_{CE}=-0.15V, I_C=12ma$	30	100	—	30	100	—	—
		$V_{CE}=-20V, I_C=24ma$	24	110	—	24	110	—	—
V_{BE}	BASE - EMITTER VOLTAGE	$I_B=-0.4ma, I_C=-12ma$	—	-0.25	-0.35*	—	-0.25	-0.35*	V
		$I_B=-1ma, I_C=-24ma$	—	-0.30	-0.40*	—	-0.30	-0.40*	V
$V_{CE(sat)}$	COLLECTOR -EMITTER SATURATION VOLTAGE	$I_B=-0.4ma, I_C=-12ma$	—	-0.06	-0.15*	—	-0.06	-0.15*	V
		$I_B=-1ma, I_C=-24ma$	—	-0.08	-0.20*	—	-0.08	-0.20*	V
V_{PT}	PUNCH - THROUGH VOLTAGE †	$V_{EB(fl)}=-1V$	-24*	—	—	—	—	—	V
$V_{EB(fl)}$	EMITTER - BASE FLOATING POTENTIAL	$V_{CB}=-25V$	—	—	—	—	-0.5	-1	V
h_{fe}	AC COMMON - EMITTER FORWARD CURRENT TRANSFER RATIO	$V_{CE}=-6V, I_C=-1ma$, f = 1KC	—	135	—	—	135	—	—
h_{ie}	AC COMMON EMITTER INPUT IMPEDANCE	$V_{CE}=-6V, I_C=-1ma$, f = 1KC	—	4	—	—	4	—	Kohm
h_{oe}	AC COMMON - EMITTER OUTPUT ADMITTANCE	$V_{CE}=-6V, I_C=1ma$, f = 1KC	—	50	—	—	50	—	µmho
h_{re}	AC COMMON - EMITTER REVERSE VOLTAGE TRANSFER RATIO	$V_{CE}=-6V, I_C=1ma$, f = 1KC	—	7×10^{-4}	—	—	7×10^{-4}	—	—
C_{ob}	COMMON - BASE OUTPUT CAPACITANCE	$V_{CB}=-6V, I_E=0$, f = 1MC	—	9	20*	—	—	—	pf
		$V_{CB}=-6V, I_E=1ma$, f = 2MC	[illegible]	—	—	—	9	20*	pf
f_{hfb}	COMMON - BASE ALPHA CUTOFF FREQUENCY	$V_{CB}=-6V, I_E=1ma$	4*	11	—	4*	12	—	MC

† V_{PT} IS DETERMINED BY MEASURING THE EMITTER - BASE FLOATING POTENTIAL $V_{EB(fl)}$ USING A VOLTMETER WITH 11 MEGOHMS MINIMUM INPUT IMPEDENCE. THE COLLECTOR - BASE VOLTAGE, V_{CB} IS INCREASED UNTIL $V_{EB(fl)}=-1$ VOLT ; THIS VALUE OF $V_{CB}=(V_{PT}+1)$. CARE MUST BE TAKEN NOT TO EXCEED MAXIMUM COLLECTOR - BASE VOLTAGE SPECIFIED UNDER MAXIMUM RATINGS.

BASE - EMITTER VOLTAGE VS COLLECTOR CURRENT



BASE - EMITTER VOLTAGE VS FREE - AIR TEMPERATURE



reverse bias voltage between the collector
with the emitter open at which there is a
increase in current flow between the colle
base. This point is known as the avalanch
breakdown, in which minority electrons, pa
PN junction, gain sufficient energy to kno
valence electrons bound to the crystal lat
raise them to the conduction band. BV_{CBO}
usually specified at some value of reverse
current. The 2N404 will avalanche between
collector and base at approximately 25 vol
20 µamps of leakage current.

(4) Emitter breakdown voltage BV_{EBO} is the max
voltage which can be safely applied betwee
and base when these elements are reverse b
with the collector open. This value is gi
specification sheets in order to indicate
a reverse bias voltage may be applied to t
of a common-emitter amplifier before the i
circuit will break down.

(5) Many manufacturers will list a collector s
voltage V_{CE}(sat). This voltage is essenti
minimum voltage necessary, at a particular
collector current, to sustain normal trans
action, and it occurs when the emitter-bas
equals the emitter-collector voltage. At
collector voltages, the base-collector jun
becomes forward biased and the current-vol
relationship changes abruptly. The curren
increase at a rapid rate limited only by a
external resistance in the collector circu

(6) The collector cutoff current is the curren
collector to base when no emitter current
applied. This is I_{CBO}. It varies with te
changes and must be taken into account whe
semiconductor is designed into equipment w
used over a wide range of ambient temperat

(7) Base to emitter voltage V_{BE} is the voltage
recommended by the manufacturer for normal
transistor action. Notice for the 2N404 V
listed for typical and maximum conditions.

, there are many characteristics of a transistor made to us by the manufacturer. We have discussed only a characteristics but, as stated earlier, in future ou will become familiar with several more important characteristics.

ly the two most important characteristics we have ssed were the maximum reverse bias between collector se (BV_{CBO}), and the power dissipation rating.

wer dissipation rating of the 2N404 (150 mW) was ly another way of expressing the safe amount of heat the collector-base junction can withstand.

er words, the transistor must dissipate power in the of heat across the junction. If the power is too there will be more than 85°C of heat generated at nction, which would destroy the device. It was found e must derate (reduce the output power) the stor for each degree of increase in ambient ature as the collector-base junction must dissipate eat it receives to the ambient air.

ist transistors *in achieving higher collector-* pation ratings, heat sinks, in which the transistors unted, have been developed. These heat sinks, or issipaters, help conduct heat away from the on, thus lowering the junction temperature (Tj).

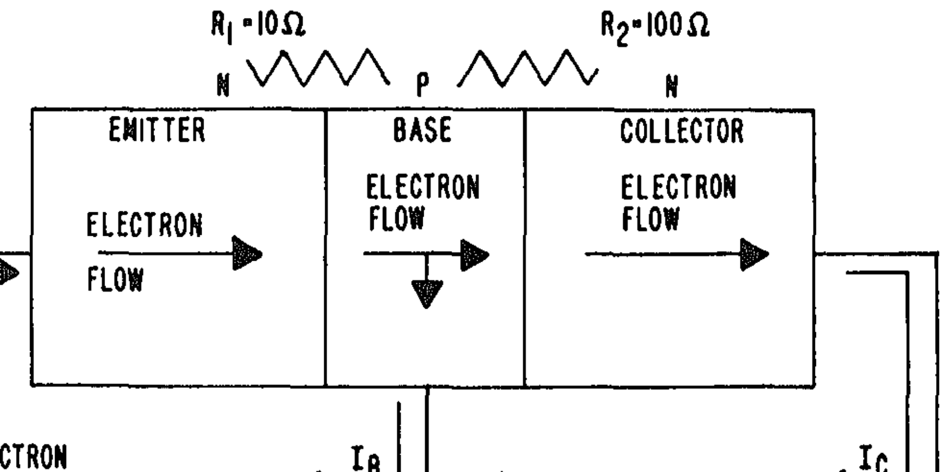
ic Circuits, NAVSHIPS 0967-00-0120, pp. 5-10 to 5-20.

ls of Radio-Electronics, Slurzburg and Osterheld,
ill Co.

or and Integrated Electronics, Kiver, McGraw-Hill Co.,
urth Edition.

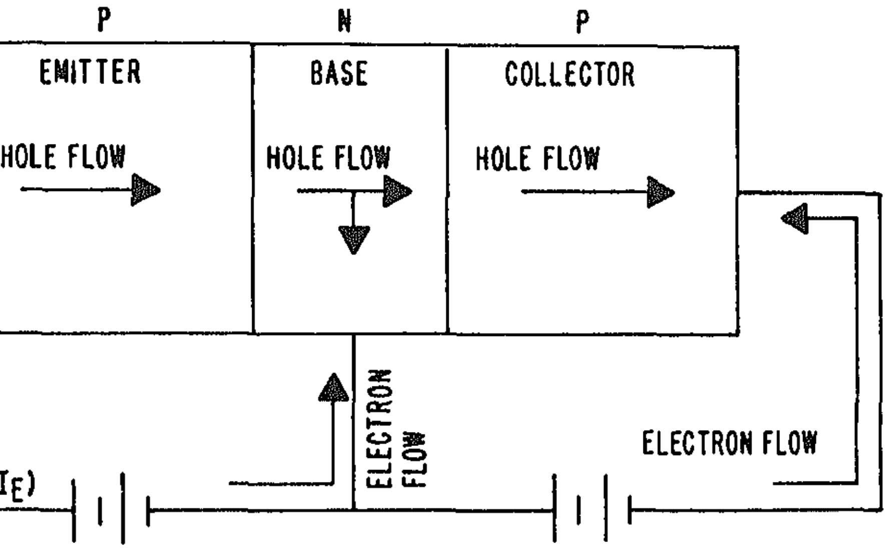
UTLINE:

sistor action



A. Analysis of the NPN Transistor

lysis of the PNP Transistor

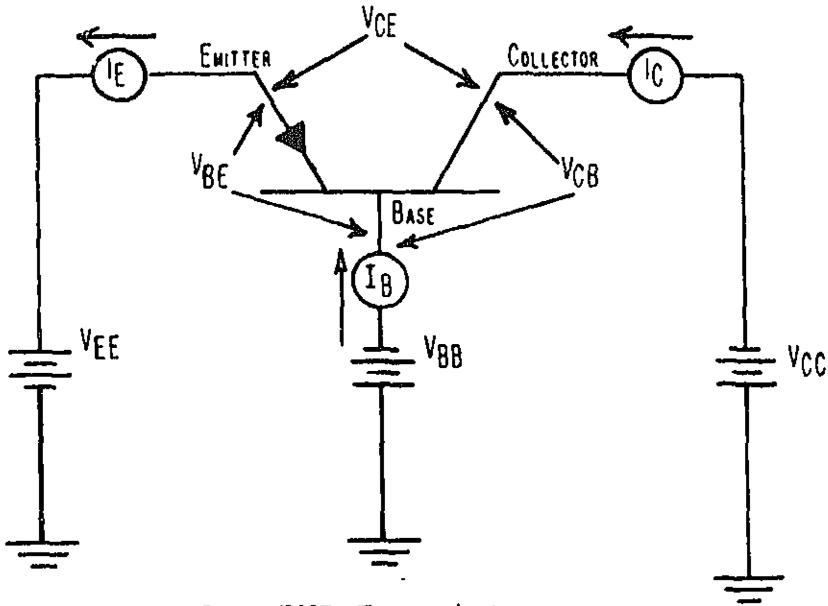


2.6 Figure 2 - PNP Transistor

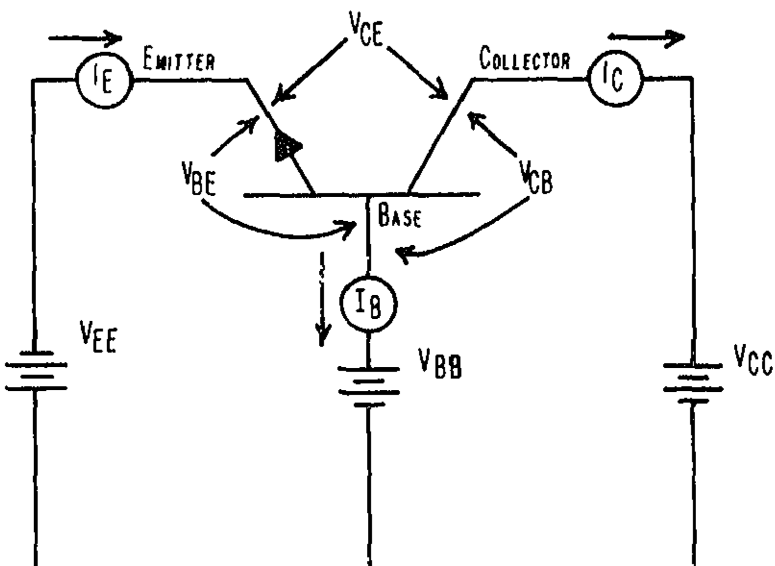
C. Mechanisms of transistor action

II. Transistor symbology and notations

A. Schematic symbols



A. PNP Transistor



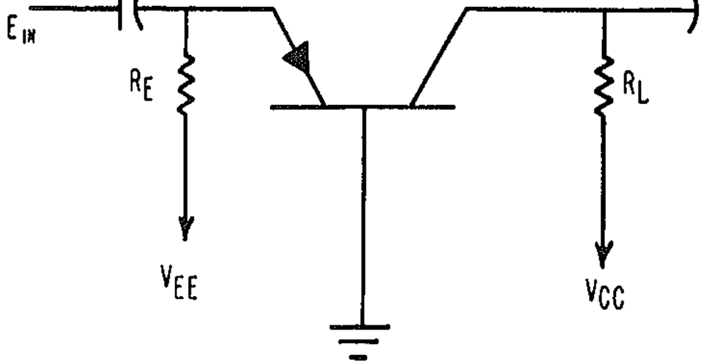
2. PNP type

3. Supply voltages

4. Terminal voltages

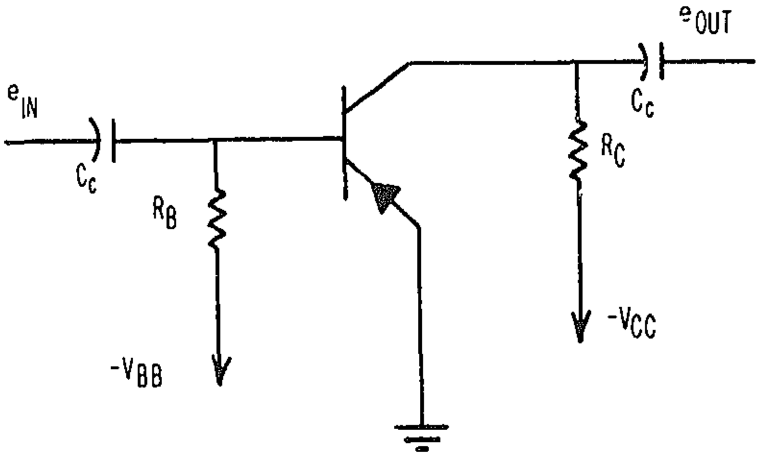
it configurations and operation

hree basic configurations



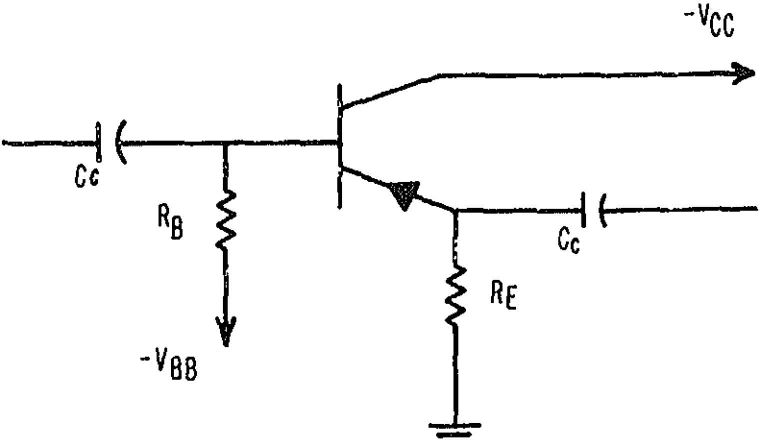
2.7 Figure 4 - Common-Base Amplifier (PNP)

non-emitter amplifier



2.6 Figure 5 - Common-Emitter Amplifier (PNP)

Collector amplifier



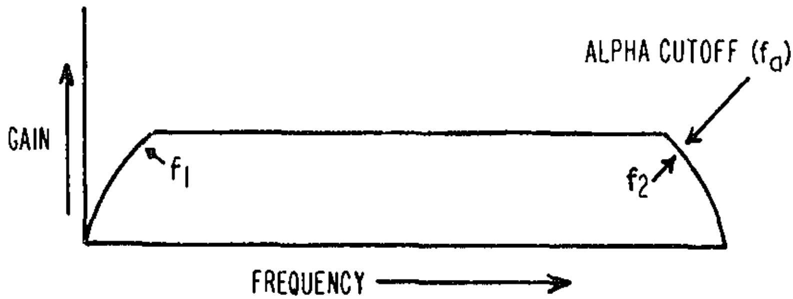
e 6 - Common-Collector Amplifier (PNP)

B. Junction temperature

ecreased current gain at high levels of transistor
urrent.

oise

E. Frequency response



2.6 Figure 7 - Transistor Frequency Response Curve

this data sheet is for you to measure, record, and
c gains and resistances of the three basic transistor
.

e amplifier

te the following schematic of the common-base ampli-
nd label components; i.e., V_{CC}, V_{EE}, R_E, R_L, etc.

measurements and calculations:

$_E$ = ______	(5) I_C = ______
$_{CB}$ = ______	(6) R_I = ______
$_B$ = ______	(7) $A_I(\alpha)$ = ______
$_{CB}$ = ______	

ic measurements

out = ______

in = ______

v = ______

ions:

rite the formula for V_{EB} for the above schematic.

2. Common-collector amplifier

a. Complete the following schematic of the common-co amplifier and label components.

b. Static measurements and calculations:

(1) V_B = ______ (6) V_{BE} = ______

(2) V_C = ______ (7) I_E = ______

(3) V_E = ______ (8) R_I = ______

(4) I_B = ______ (9) $A_I(\gamma)$ = ______

(5) V_{BC} = ______

c. Dynamic measurements:

= ______

= ______

=

t the bias voltages correct for normal transistor
eration?

____

at is the voltage gain characteristic of the common-
llector amplifier? ________________________________

Instructor's initials __________

tter amplifier

te the following schematic of the common-emitter
ier and label components.

(4) I_B = ______________ (9) A

(5) V_{BE} = ______________

c. Dynamic measurements:

(1) e_{out} = ______________

(2) e_{in} = ______________

(3) A_v = ______________

d. Questions

(1) What would happen to forward bias i

____

(2) Are the bias voltages correct for n
operation?

____

Instructor's

sistor means setting the d-c voltages and currents of to certain chosen values to establish an operating a-c signal. A bias circuit employs resistors and d-c to set the various voltages and currents at the pre- ues. These d-c voltages and currents must be such he transistor's ratings are exceeded; that is, they the permissible operating point region.

Circuit Analysis, NAVAIR 00-80-T-79, Chapter 8.

Kiver, Transistor and Integrated Electronics. N. Y., McGraw-Hill Book Company, 1972, Fourth

on

he a-c signal is applied to the transistor, the stor's voltages and currents vary about the operating Only a portion of the permissible operating point is such that the amplification is linear; this n of the permissible operating point region is called near operating region. The entire signal swing must nin the linear operating region for the input to be ied without appreciable distortion.

are two major reasons for the difficulty in sustain- desired operating point. First, as was noted in duction to Semiconductors," the characteristics of nductor materials are temperature dependent. Second, aracteristics of different transistors of the same ill vary from unit to unit. Consequently, when s transistors are placed in the same circuit, the ion will vary somewhat unless stabilizing measures ken.

transistor and the means for removing heat from the
Changes in temperature affect three transistor quant
*I_{CBO}, β, and V_{EB}. β and I_{CBO} will rise as the temp
increases. The V_{EB} which is necessary to produce a
emitter current decreases as the temperature increas
these, the most serious variation is experienced by

1. Reverse-Bias Collector Current (I_{CBO}). I_{CBO} (so
referred to as I_{CO}) is normally measured at a T_A
temperature) of 25°C (see figure 1). Note that
minority current, and flows in the same directio
collector current if the transistor was properly
This current I_{CBO}/I_{CO} is the same type current
that flows in any PN junction under a reversed b
condition (see figure 2). The current flow in t
biased condition is almost constant and independ
voltage prior to the breakdown point.

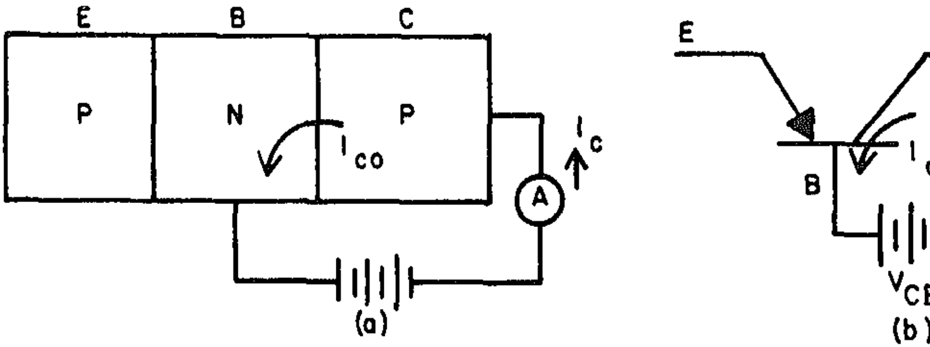
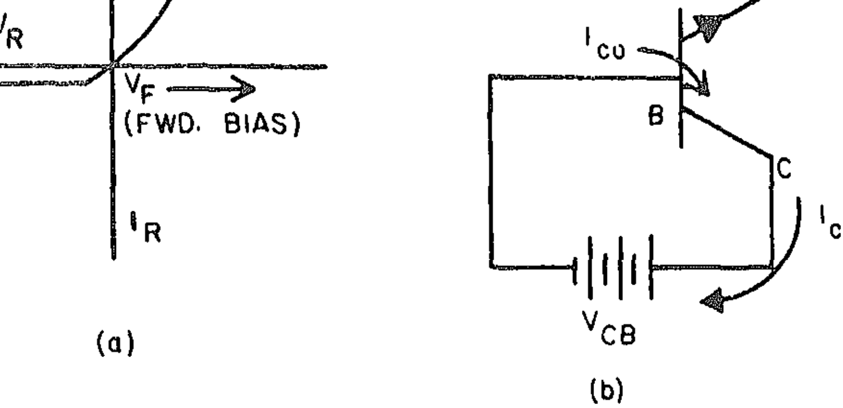


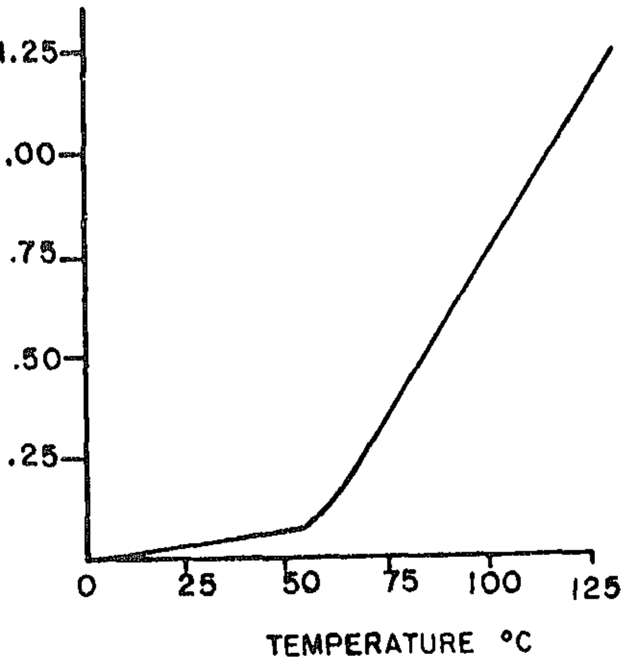
Figure 1

a. *Variations of* I_{CBO}/I_{CO} with temperature of t
collector-base junction is shown in figure 3
current value varies from almost zero at 10°
well over 1 milliampere at 125°C. Note that
temperatures below 10°C, I_{CBO} causes no prob
I_{CO} doubles for every 10°C rise in germanium
every 6°C rise in silicon.



PN Junction Characteristics

Figure 2



base are high in value, electrons from the collect can accumulate in the base region. Such an accumulation of electrons will cause an increase of emit hole into the base, increasing collector current. Increased collector current would raise the temper of the collector-base junction, and cause an incre in I_{CO} (figure 3). The cycle would continue until severe distortion occurs, the transistor becomes i operative, or it destroys itself. THIS CONDITION BE MINIMIZED BY AVOIDING THE USE OF HIGH-VALUED RE SISTORS IN THE BASE LEAD.

Beta - β is the current gain of the common-emitter tra sistor configuration. It is the ratio of a change in collector current (ΔI_C) caused by a change in base cur (ΔI_B). I_{CBO} flows through the base lead in opposite direction to I_B (figure 4), increases I_{CBO}, causes I_C t increase, and I_B to decrease. Therefore, for a set va of I_B β would increase and shift the operating point.

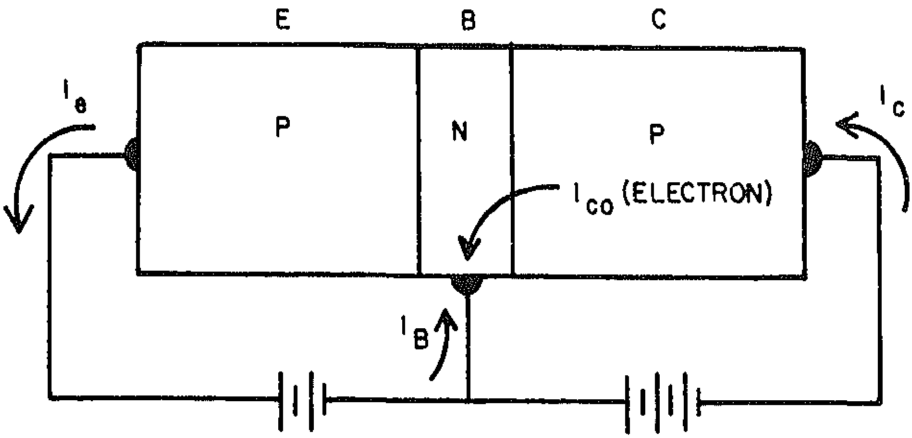
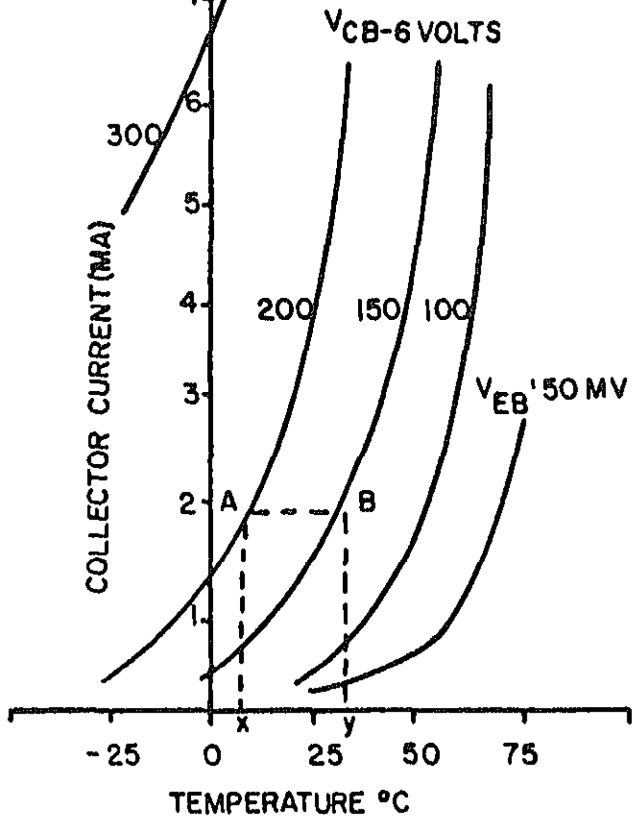


Figure 4

V_{EB} - Figure 5 indicates the variation of collector cu with temperature. Each curve is plotted with a fixed collector-base voltage (V_{CB}) and a fixed emitter-base



ariation of Collector Current with
Transistor Temperature

Figure 5

ethod of reducing the effect of the NEGATIVE RATURE COEFFICIENT of resistance is to place a value resistor in the emitter lead. Essentially, causes the variation of emitter-base junction tance to be a small percentage of the total re- nce in the emitter circuit. The external resistor s (overcomes) the junction resistance; the re- r is referred to as a <u>swamping resistor</u>.

ond method of reducing the effect of th rature coefficient of resistance is to er-base forward bias as the temperatur

$$\frac{\text{Difference in forward bias}}{\text{Difference in temperature}} = \frac{50 \text{ mV}}{20°C} = 2.5$$

This calculation indicates that collector cur
not vary with emitter-base junction resistanc
forward bias is reduced 2.5 mV/°C for increas
temperature, or increased 2.5 mV/°C for decre
temperature.

. Common-Emitter Amplifier

1. The common-emitter amplifier is the most commonly
   amplifier because it has the following character

   a. Current gain; $\beta = \frac{\alpha}{1-\alpha}$

   b. Voltage gain $\cong \beta \cong \frac{R_O}{R_i}$

   c. Highest power gain

   d. Easier to cascade because $\frac{R_O}{R_i}$ is more closely

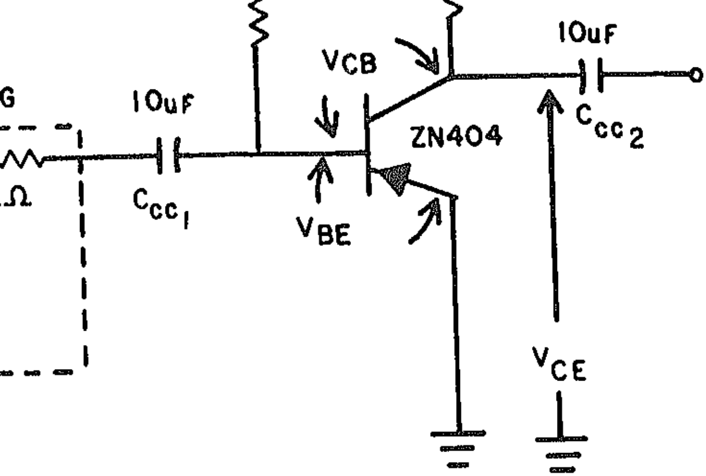
   However, it must be stabilized because of unit to
   variations, and temperature instability.

   (1) There are several biasing arrangements used
   common-emitter amplifier to compensate for it
   stability. Constant base current biasing is
   figure 6 and will be used to analyze basic b

$$I_B = \frac{V_{CC} - V_{BE}}{RB} = \frac{5.8V}{1M} = 5.8 \ \mu A$$

$V_{BE} \approx .2V$ for germanium; since $R_B >>$ the d
resistance, I_B will be limited primarily by

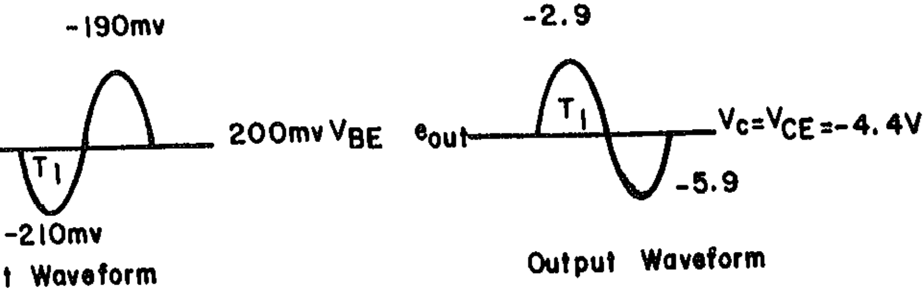
$$I_C = \beta I_B = 100 \times 5.8 \ \mu A$$



stant-base-current bias common-
emitter amplifier

Figure 6

re, the collector voltage $V_C = V_{CE}$ is 4.4 volts. put waveform will vary around this point (4.4 as shown in figure 7.

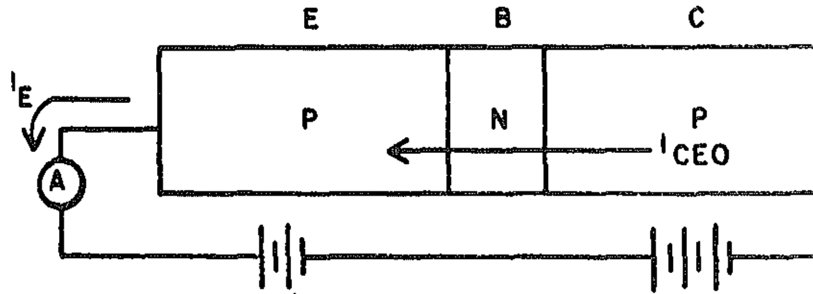


$$\cdot = \frac{3.0v}{20mv} = 150 \qquad \text{Eq (1.5)}$$

out waveform versus input waveform

Figure 7

parameter I_{CBO} was not included. I_{CBO}
current that flows collector to base wi
emitter open. However, transistor acti
occur with the emitter open. If, on th
I_{CBO} flowed only in the collector-base
would cause no serious problem. But, i
is constructed that has a high resistan
base lead, it will appear open to this
current. This will cause a current to f
I_{CEO}* (figure 8). These minority carri
base



I_{CEO} in PNP Transistor

Figure 8

circuit and become majority carriers.
emitter, this is the same as an increas
bias current. The emitter injects β +
the base to offset the negative charge
β holes will diffuse through the base a
amount that will recombine with I_{CO}.

Mathematically:

$$I_{CEO} = I_{CBO}\ (B+1) = I_{CO}(B+1)$$

The collector current (I_C) is:

$$I_C = \beta I_B \text{ (Eq 1.2)} + I_{CEO}$$

$$= \beta I_B + I_{CEO}$$

$$= \beta I_B + I_{CO}(B+1)$$

$(100)(5.8\ \mu A) + 5\ \mu A\ (101)$

$(1.085\ mA)$

$V_{CC} - I_C R_L = 6 - (1.085\ mA)(2.76\ k\Omega)$ (Eq 1.8)

$6 - 2.99 \approx 3$ volts

ual operating point would be V_{CE}=3 volts and he output signal would be symmetrical if the emained 20 mV p-p and A_v 150. However, if the ture increases and cause I_{CO} to increase, I_C will e. This would create more heat and more I_{CO}. ocess is called thermal runaway and could damage nsistor if R_L is very small. In our example, if perature increased and caused I_{CO} to increase to a small current compared to I_C, the new operating ill be:

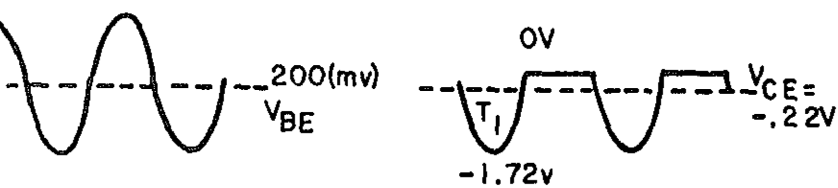
$V_{CC} - I_C R_L$ (Eq 1.9)

$V_{CC} - \{100 \times 5.8\mu A + (15\mu A)(101)\}(2.76\ k\Omega)$

$6 - 5.78$

$-.22V$ (saturation)

nput signal and A_v remained the same, then:



Input Waveform (b) Output Waveform

Figure 9

$\overline{\Delta I_{CBO}}$

It indicates the change in collector curr
change in I_{CBO}. The optimium value of S
equals 1, then I_C will change only by the
I_{CBO}. This is an idealized objective and
realizable with ordinary measures. The v
is always greater than 1 for the common-e
fier. However, it should be remembered t
the value of S is to 1, the better.

Apply equation 1.10 to figure 6.

$$S = \frac{\Delta I_C}{\Delta I_{CBO}} = \frac{\Delta I_{CEO}}{\Delta I_{CO}} = \frac{1{,}010\,\mu A}{10\,\mu A} = 101$$

The stability factor of the unstabilized
amplifier (figure 6) approximately equals
current gain. We will see in the followi
how this value is improved by various sta
schemes.

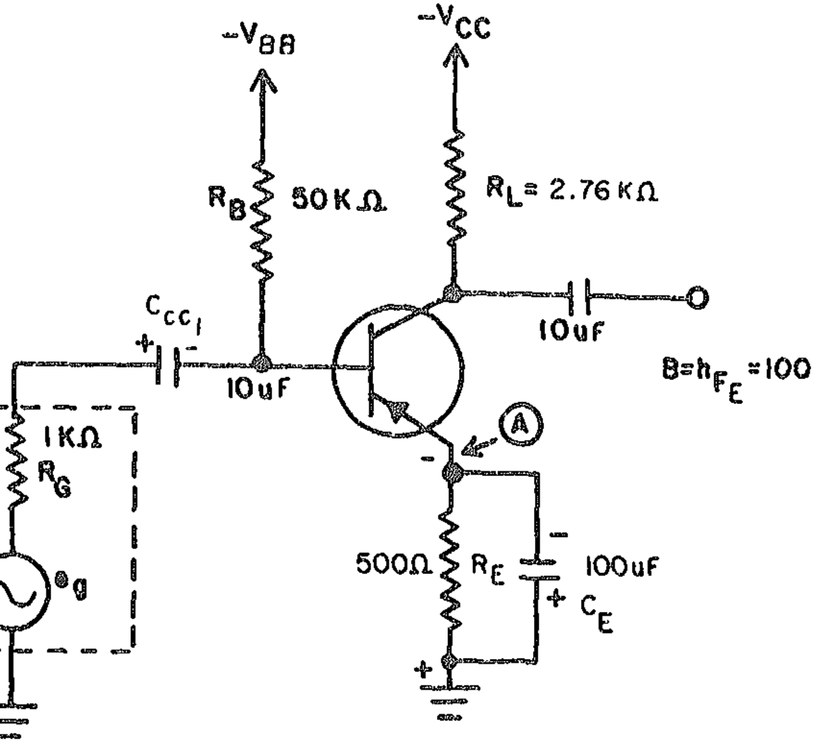
b. Figure 10 is a bias scheme used to improv
of the circuit. The addition of an emitt
(swamping resistor) increases the stabili
circuits by:

(1) Compensating for the negative coeffic
tance of the emitter base junction.

(2) Unit to unit variations, since this v
same as temperature variations.

(3) Providing a constant current source.

The resistor R_E adds the disadvantage of
since it develops a voltage that is degen
input signal. If greater gain is require
passed with a capacitor. R_B is reduced t
bias scheme is called constant emitter cu
since it attempts to maintain I_E constant
in I_E would cause a more negative voltage
oped at point (A) in figure 10, which wou
forward bias and reduce transistor curren



r Current Biased Common Emitter Amplifier

Figure 10

the circuit. Under dynamic conditions, the s at a-c ground due to the bypassing action of hould be remembered that bias stability deals conditions and C_E simply keeps the emitter at d. Through the use of calculus it can be at the stability factor for the circuit in is

$$\frac{\Delta I_C}{I_{CBO}} = \frac{(R_B+R_E)(\beta+1)}{R_B+(1+\beta)R_E} \qquad \text{(Eq 1.11)}$$

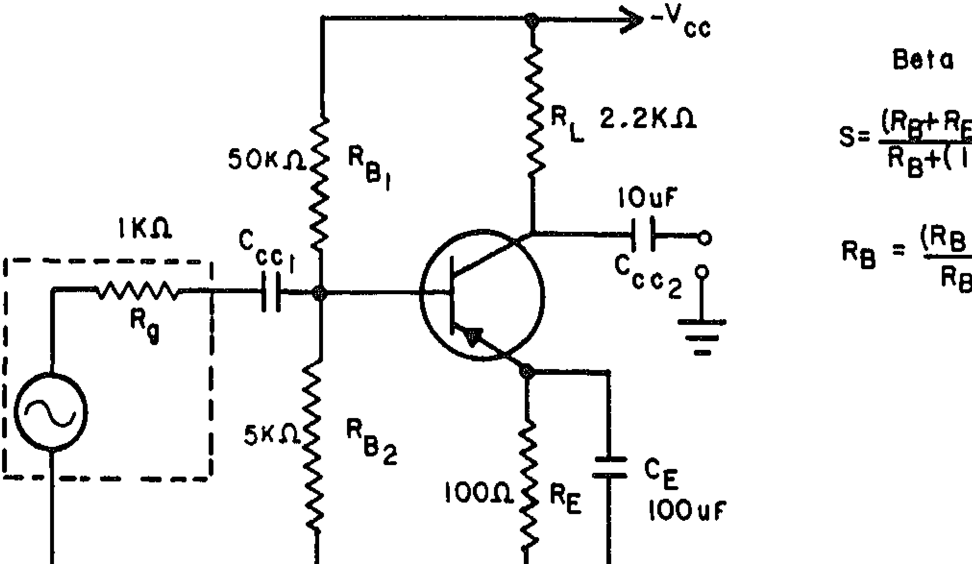
$$= \frac{(50\times10^3 + .5\times10^3)(101)}{50\times10^3 + (.5\times10^3)(101)}$$

$$= 5100.5 \times 10^3$$

zero, the stability factor approaches ideal. Fur
if R_E approaches zero the stability factor approa
B+1. Therefore, for good stability R_B should be
small as possible and R_E as large as possible. C
cannot make R_E larger and R_B smaller indefinitely
ever, even though R_E can be a-c bypassed by a cap
the power supply voltage must be made larger as R
increased. For R_B, a lower limit set by the shun
effect on the a-c signal if the stage is capaciti
direct coupled; if it is transformer coupled, the
limit on R_B is set only by the magnitude of the b
voltage.

d. The stability, it is noted, is affected by R_E, R_B
Beta of the transistor. Note also, that the stab
does not depend on R_L. The stability factor used
circuit will depend on whether the I_C variation i
missible, in terms of signal swing, permissible p
dissipation, or the conditions for thermal runawa
not, then R_E must be raised or R_B lowered until
suitable condition is found.

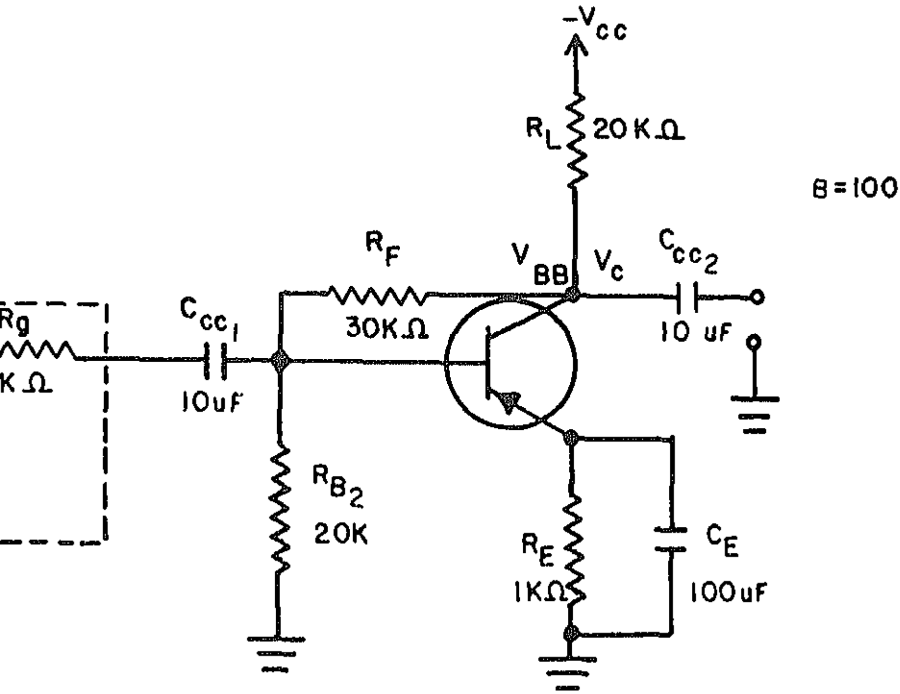
e. The most frequently used biasing circuit is shown
figure 11 where an additional resistor is added i
base circuit.



to establish the proper forward bias.
uld decrease the stability of the circuit.

res 10 and 11, the swamping resistor develops
ative d-c current feedback. If a-c stability is
sired, the removal of the emitter bypass capaci-
) will provide a-c current feedback.

general method for stabilizing the operating
onsists of using direct voltage feedback with
current feedback (figure 12).

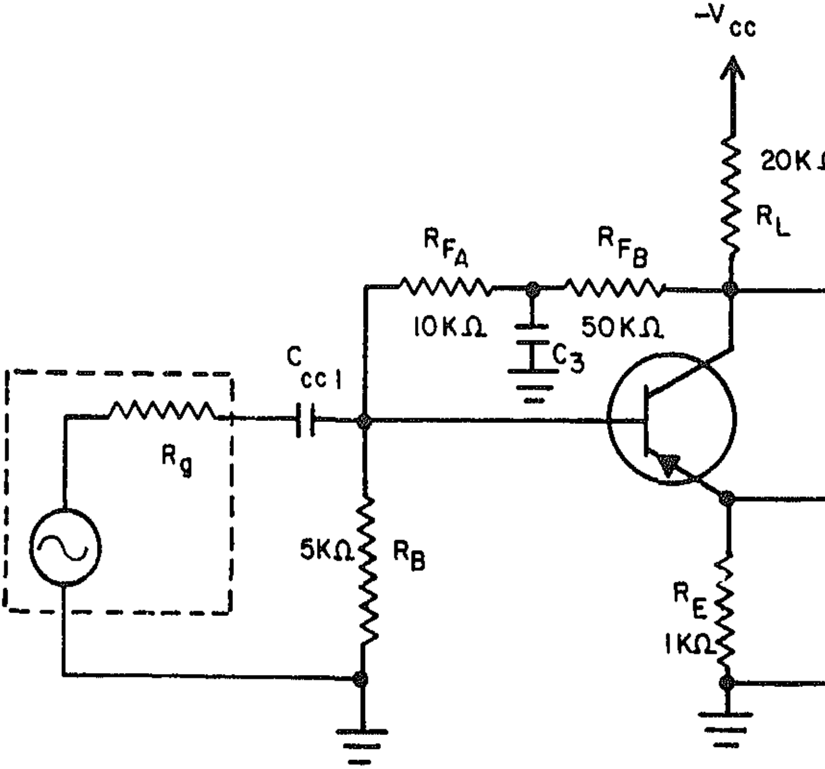


nstant-Collector-Voltage Biased
Common-Emitter Amplifier

Figure 12

feedback is defined as that situation when the
of signal fed back to the input (from the output)
upon a voltage in the output circuit.

If greater gain is required, the circuit c
as in figure 13. The capacitor C_3 bypasse
generation without altering the d-c circu
because $R_{FB}||R_L$ and reduces the a-c load



Constant-Collector-Biased Common-Emitter Amp

Figure 13

i. These, are the stabilizing schemes and eq
on the common emitter. The choice betwee
current-feedback is largely determined by
the d-c load resistance. If the d-c R_L i
usually the case for RC-coupled amplifier
feedback (emitter at a-c and d-c ground)
as the current type. For transformer cou
the d-c R_L is low, current feedback is mu

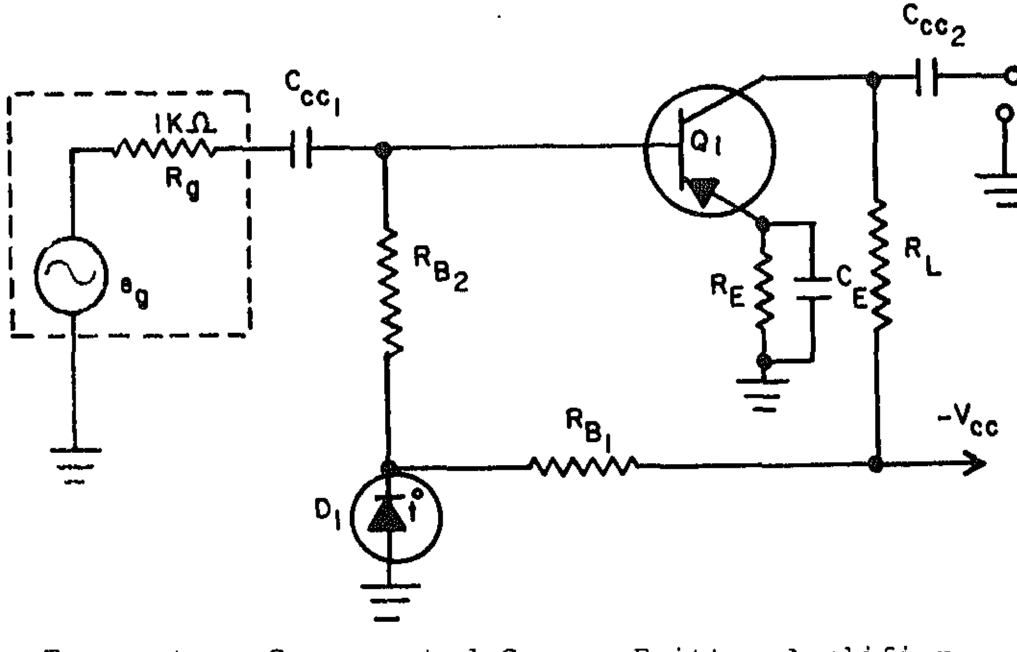
(1) Determine the appropriate S value and then use various d-c equations to fix the circuit compo values which will give the S.

(2) Decide upon the component values by the usual considerations and then check the resulting S.

tional Stabilizing Techniques

When using temperature-sensitive elements for stabilit idea is to cause the circuit conditions to change with temperature so that the changes effected by the transi are compensated.

Figure 14 is an example using a diode (D_1) that has si characteristics as the emitter-base junction of Q_1 (ne temperature coefficient). Any temperature variation w affect the base voltage and correct I_B to compensate f change. Note also that current feedback is still used



Temperature-Compensated Common-Emitter Amplifier

a. Capable of the highest voltage gain of the thr configurations;

$$A_V \approx \alpha \left(\frac{R_O}{R_i}\right)$$

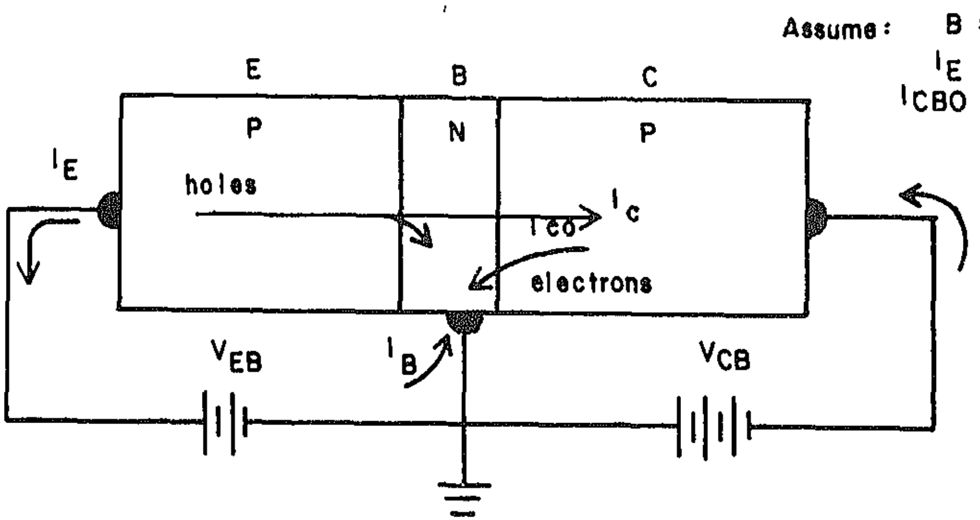
b. A current gain called Alpha = $\frac{\Delta I_C}{\Delta I_E}$ always less than one.

c. Very low input resistance; high output resista

d. Used mainly where the matching of a low to a h resistance is required.

e. Ideal stability factor in the basic circuit configuration.

2. Figure 15 will be used to illustrate the common-ba amplifier, its current flow and direction of curre



Current Flow in a PNP Transistor

Figure 15

I_C

$- 4.95mA$

llector current did not include the effect of

$\alpha I_E + I_{CO}$

$(.99)(5{,}000\ \mu A) + 25\ \mu A = 4{,}975\ \mu A$

$- \alpha) - I_{CO}$

$\mu A\ (1 - .99) - 25\ \mu A$

$- 25\ \mu A$

lear that if I_{CO} decreases I_B by its increase; constant and I_C will change only by I_{CO}. an ideal stbility factor.

or using constant emitter current biasing is igure 16.

$- I_E R_E = 6 - \{1mA \times 5.8k\} = + .2V$ (Eq 1.13)

$I_C R_L = V_{CC} - (\alpha I_E + I_{CO})(R_L)$ (Eq 1.14)

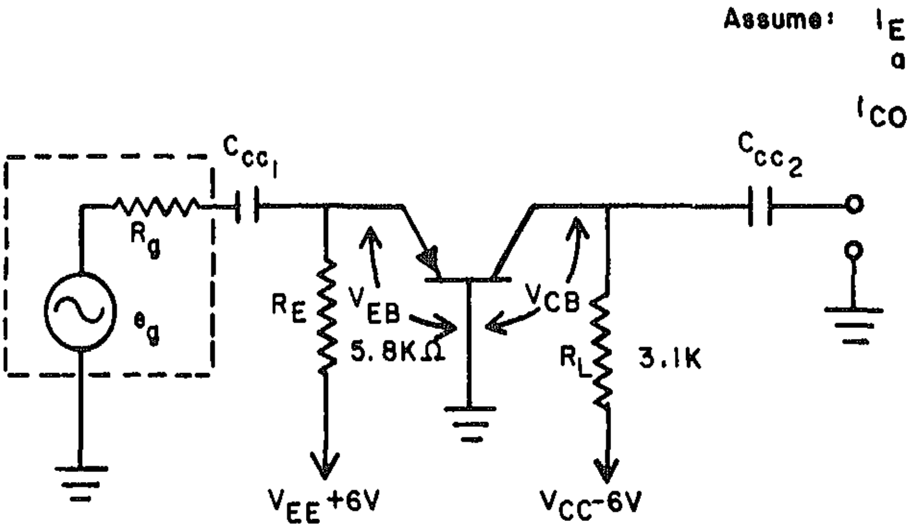
$\{(.99)(1000\mu A) + 5\mu A\}\{3.1k\}$

lts

V_B (Eq 1.15)

$-(0)$

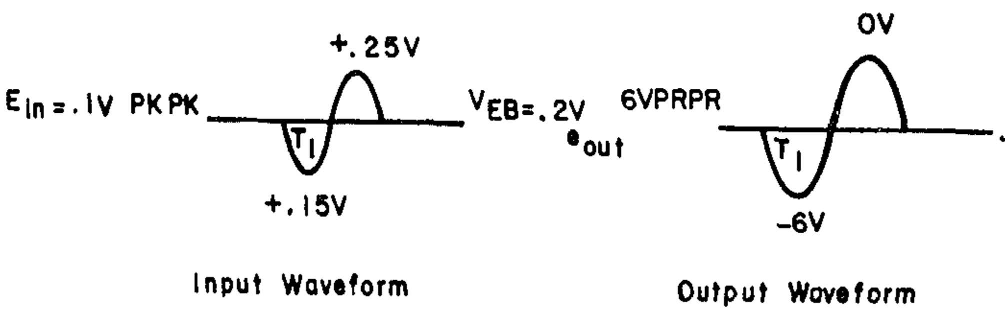
olts



Constant Emitter Current Biased Common Base Amplifier

Figure 16

With the bias voltages computed, the amplifier is pr
biased. Assuming a voltage gain of 60 and input sig
.1 volts p-p, the output signal is given in figure 1
operating point is 3 volts (V_{CB}) and the maximum out
without distortion is used.



$\Delta I_{CBO} \quad R_B + (\beta+1)R_E$

$S = \frac{R_E(\beta+1)}{R_E(\beta+1)} = 1$; ideal stability

change in I_{CO} will change I_C by the same amount. current that becomes I_{CEO} simply aids the circuit in stability. A disadvantage of this circuit is that requires two power supplies. One power supply could used with a voltage divider network; however, one t remember any resistance added in the base increases stability factor.

ector Amplifier

mon-collector amplifier has the following eristics:

highest current gain; $\gamma = \beta + 1$

tage gain less than one; $A_V = \gamma \left(\frac{R_O}{R_i}\right)$

h input resistance; low output resistance.

d mostly for impedance matching.

d a-c and d-c stability due to its degenerative dback.

common-collector amplifier is shown in figure 18.

s voltages are as follows:

$$_{BB} - I_BR_B - I_ER_E \qquad \text{(Eq 1.16)}$$

$$4 - \{(27 \times 10^{-6})(30 \times 10^3)\} - \{(101)(27 \times 10^{-6})(1.1 \times 10^3)\}$$

.19 volt

$$= V_{CC} - I_ER_E \qquad \text{(Eq 1.17)}$$

$$6 - \{(101)(27 \times 10^{-6})(1.1 \times 10^3)\}$$

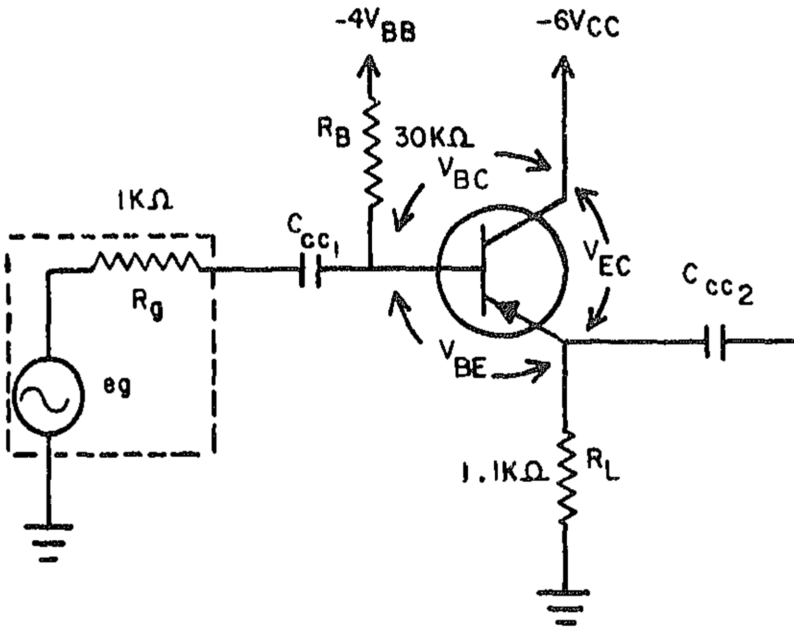
$V_{BC} = V_{CC} - (V_{BB} - V_{RB})$

$$= -6 - \{4-(-.8)\}$$

$$= -6-(-3.2)$$

$$= -2.8 \text{ volts}$$

As

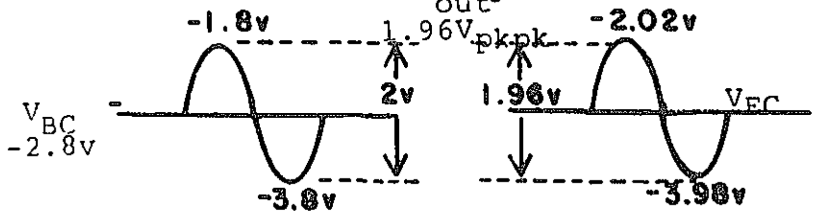


Basic Common-Collector Amplifier

Figure 18

If a 2V p_{-p} signal was applied to the amplifi
would be as shown in figure 19.

2. The S of this circuit is approximtely equal t
R_B to R_L. Equation 1.9 could be used to anal
circuit also. The common collector amplifier

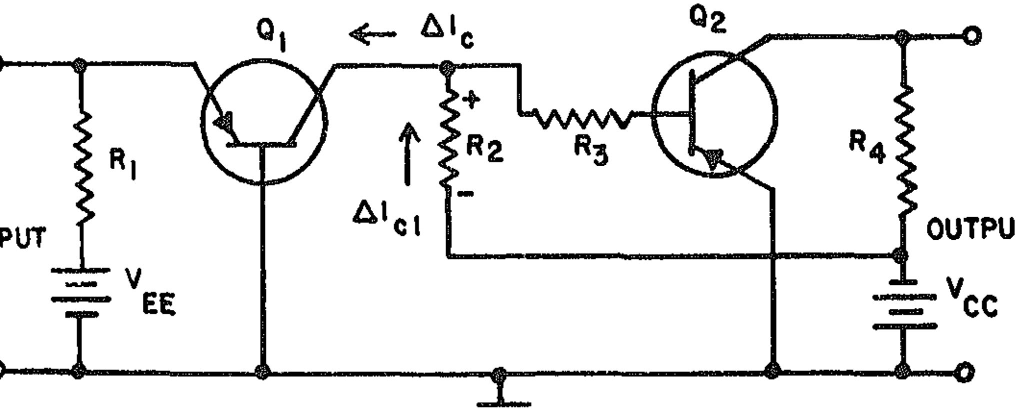


(a) INPUT WAVEFORM (b) OUTPUT WAVEFORM

Output Waveform Versus Input Waveform
Common-Collector Amplifier

Figure 19

amplifier - Sometimes direct-coupled amplifiers are us
ilize I_C variations. An example is given in figure 20
amplifier amplifies d-c voltage and very low frequency
als. This circuit is arranged so that an increase in
ector current caused by a temperature rise in transist
reduce the forward bias in transistor Q2. The voltag
across resistor R_2 opposes the forward bias on Q_2. B
ecting the values of resistors R_2 and R_3 so that the vo
across R_2 is the larger, the change in I_C of Q_1 will
tendency of transistor Q_2 collector current to increas
erature.



2. Items that should be remembered concerning bias
ments are:

a. Reverse-bias collector current I_{CBO}, also c
increases rapidly at high temperatures and
increased collector current.

b. Emitter-base junction resistance decreases
creasing temperature and causes increased e
current.

c. The stability factor (S) is defined as the
change in collector current (Δ_{IC}) to a char
minority current (ΔI_{CBO}) and is expressed a

$$S = \frac{\Delta_{IC}}{\Delta I_{CBO}}$$

d. An emitter swamping resistor minimizes vari
emitter current caused by variations in emi
junction resistance.

e. Zero base resistance limits the accumulator
carriers (I_{CO}) in the base region and there
the.increase in emitter current due to this

f. The basic common-base amplifier (figure 16)
best temperature stability because it uses
swamping resistor and zero base resistance.

g. The basic common-emitter amplifier (figure
poor temperature stability because it uses
resistor and zero emitter resistance.

h. The temperature stability of the basic comm
amplifier (figure 18) depends upon the rati
resistance to emitter resistance.

Circuit Analysis, Vol. I, NAVAIR 00-80-T-79,

Kiver, Transistor and Integrated Electronics. New
, McGraw-Hill Book Company, 1972, Fourth Edition.

LINE:

l Information - Biasing

ional Analysis of the Common-Emitter Amplifier

asing

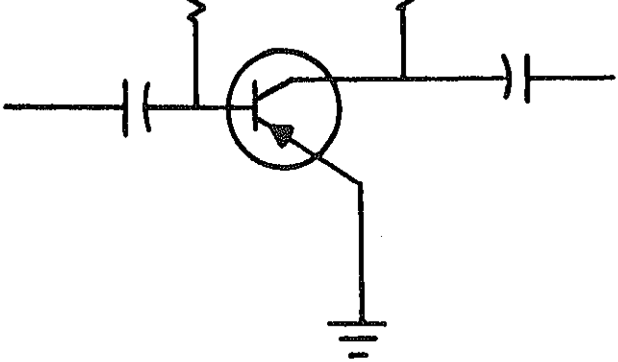
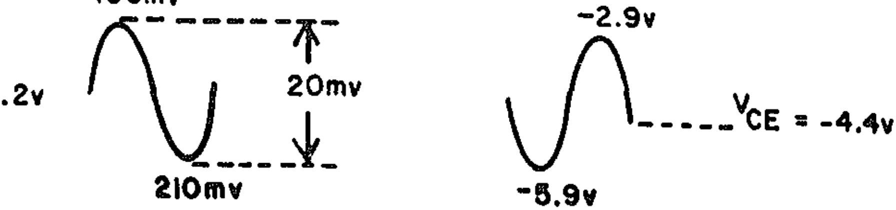


Figure 1



(a) Input Waveform (b) Output Waveform

Figure 2

Temperature variations

Reversed bias collector Currect (I_{CBO})

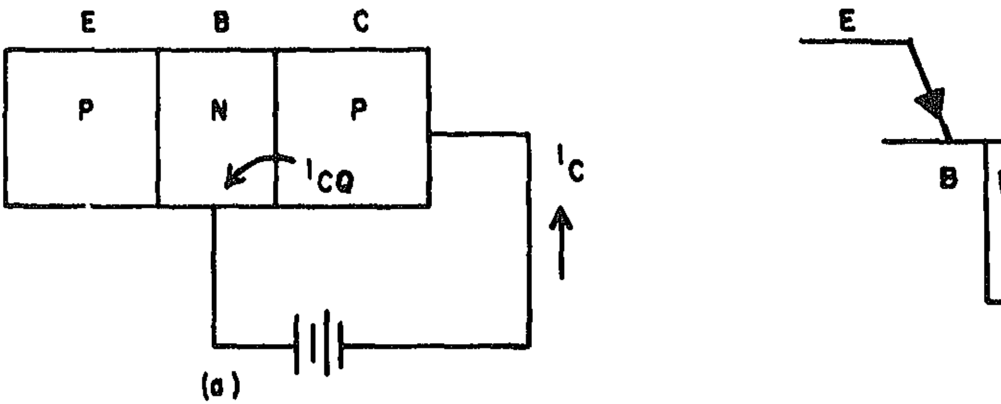


Figure 3

D, Beta

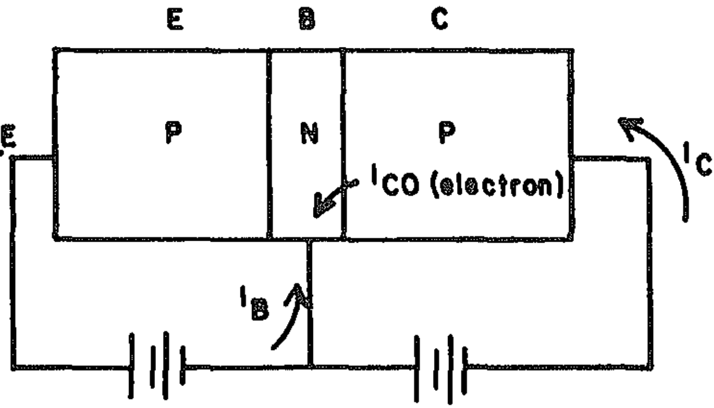
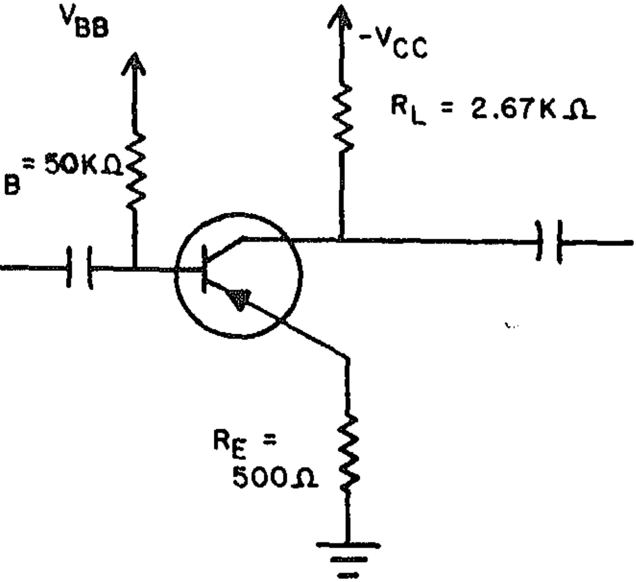


Figure 4

ant-emitter-current biased common-emitter amplifier



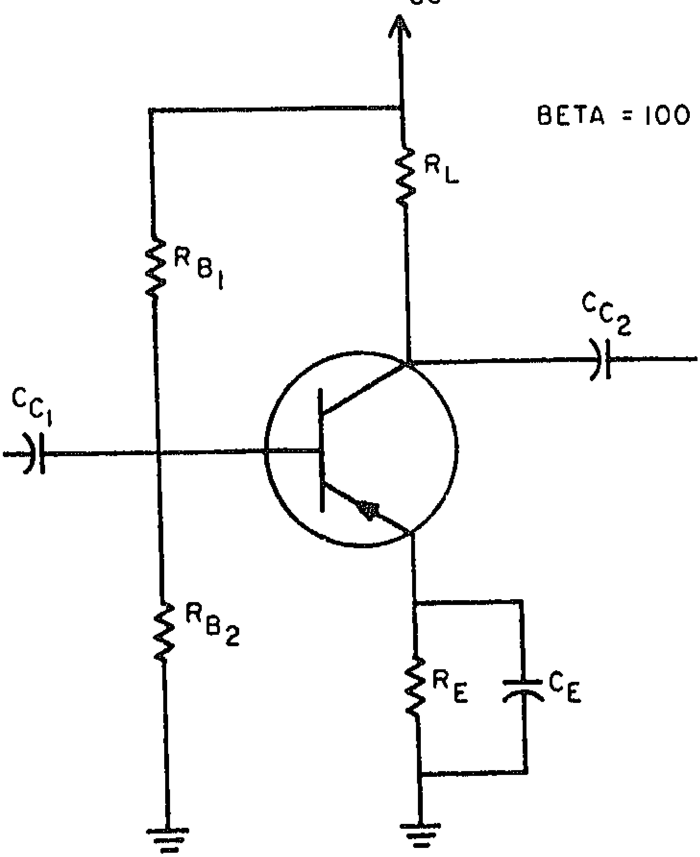


Figure 6

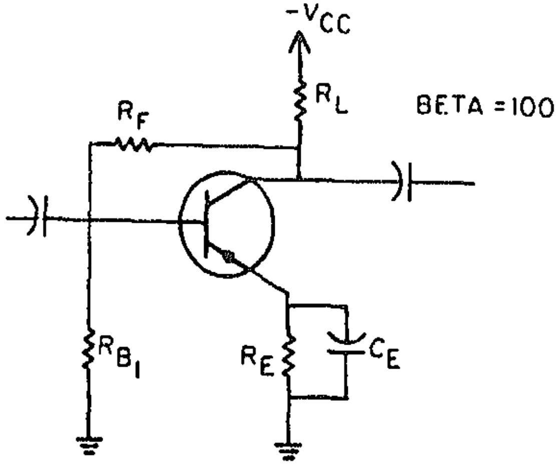
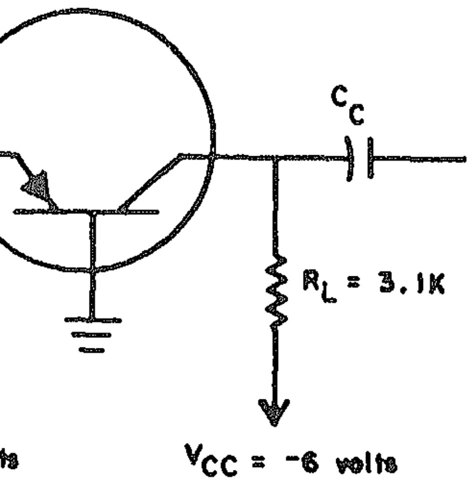


Figure 7

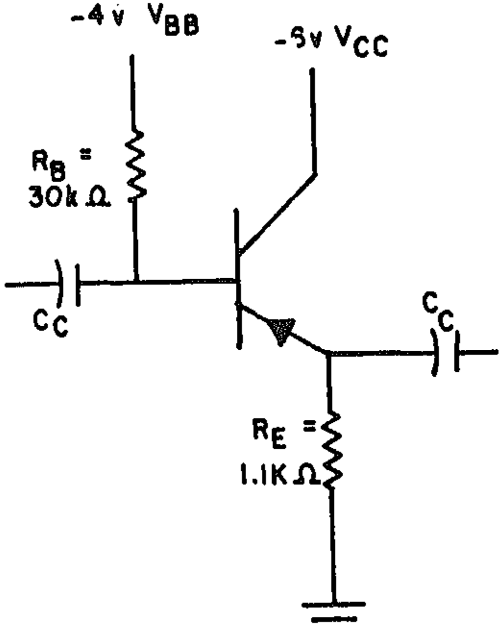


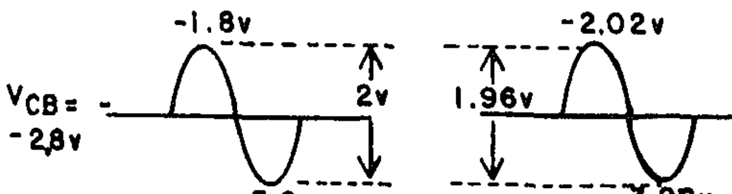
ASSUME: I_E = 1 mA
ALPHA = .99
I_{CO} = 5 uA

V_{CB} = -3v

V. Operational Analysis of the Common-Collector

A. Biasing





the data sheet is for you to record the effects of a transistor's operating point. You will apply heat r, and you will measure and record the resulting rent with and without compensating circuit components.

e effects

ishing operating conditions:

: = ______________

$_{E}$ = ______________

$_{E}$ = ______________

tput wveform

______________ V_{p-p}

: = __________

$_{CE}$ = __________

s of increased temperature:

V_{BE} = ____________

ΔV_{BE} = ____________

$_{C}$ = ____________

ΔI_{C} = ____________

tput waveform

______________ V_{p-p}

$_{CE}$ = __________

(2) How is V_{BE} affected by temperature changes?

(3) Does temperature affect fidelity? Explain.

(4) What would be the result of a transistor's to extreme heat for a prolonged period of t

____

Instructor's initials

2. Reducing temperature instability with the addition resistor.

a. R_7 equals 10 kΩ

(1) I_C = ________

(2) I_C after heating = ________

(3) ΔI_C = ________

b. R_7 equals 100 kΩ

(1) I_C = ________

(2) I_C after heating = ________

(3) ΔI_C = ________

c. E_{out} = ________

d. E_{in} = ________

e. A_v = ________

.ons

oes the introduction of an emitter resistor improve
ransistor temperature stability? Why?

oes the size of the emitter resistor affect transistor
emperature stability? Explain.

hat is a disadvantage of using an emitter resistor?

ow can the above disadvantage be compensated for?

oes the emitter bypass capacitor stabilize I_{CO}? Why?

Instructor's initials ________

f R_B and R_E on temperature stability and A_v.

____

ter heat = ________

____

= ________

____

j. E_{out} = ______________

k. E_{in} = ______________

l. A_V = ______________

m. Questions

(1) In terms of stability, what conclusion reg
ratio of R_B to R_E can be drawn from this p
experiment? Explain?

____

____

(2) Why is it desirable to have I_{CO} flow throu
collector-base junction rather than both t
base and the emitter-base junction: Expla

____

____

____

Instructor's initia

4. Constant collector-voltage feedback to improve sta

a. Operation at ambient temperature:

(1) I_C = ______________

(2) E_{out} = ______________

(3) E_{in} = ______________

(4) A_V = ______________

(5) I_C with heat applied = ______________

h heat applied = ________________

____

constant-base voltage bias to constant-collector
as, explain any difference in their effects on
tability.

____

____

____

Instructor's initials ________

Adams, <u>Basic Mathematics for Electronics</u>. New York:
l Book Company, Ind., Third Edition, Chapters 34 and

tronics, Volume 1. NAVPERS 10087-C. Washington,
ted States Government Printing Office, 1979,
, pages 221-231.

LINE:

of Logarithms.

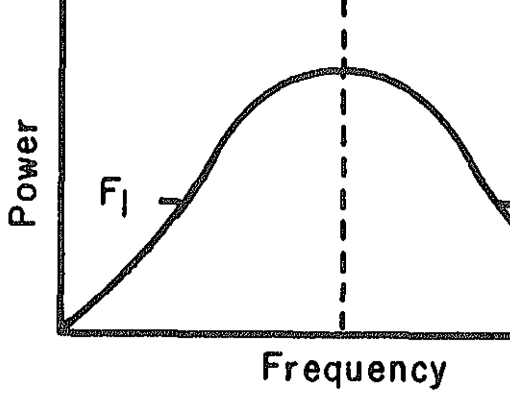


Figure 1 Bandwidth Cu

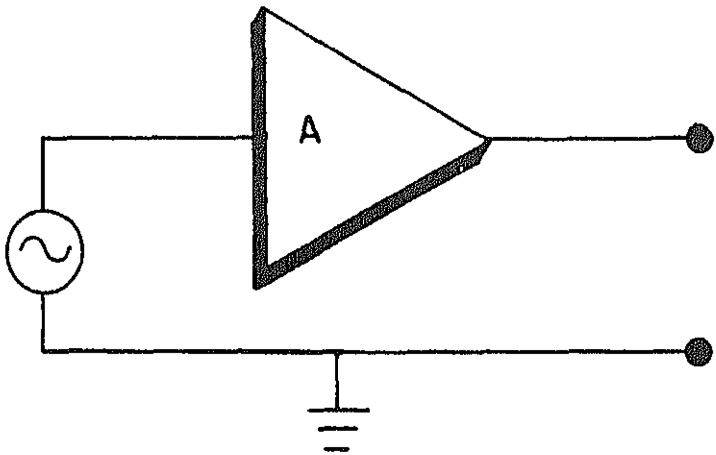
3	4771	4914	5051	5185	5315	5441	5563	5682	5798	5911
4	6021	6128	6232	6335	6435	6532	6628	6721	6812	6902
5	6990	7076	7160	7243	7324	7404	7482	7559	7634	7709
6	7782	7853	7924	7993	8062	8129	8195	8261	8325	8388
7	8451	8513	8573	8633	8692	8751	8808	8865	8921	8976
8	9031	9085	9138	9191	9243	9294	9345	9395	9445	9494
9	9542	9590	9638	9685	9731	9777	9823	9868	9912	9956
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
48	6812	6821	6830	6839	6848	6857	6866	6875	6894	6893
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067

50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
51	7076	7084	7093	7101	7110	7118	7126	713
52	7160	7168	7177	7185	7193	7202	7210	7218
53	7243	7251	7259	7267	7275	7284	7292	730
54	7324	7332	7340	7348	7356	7364	7372	738
55	7404	7412	7419	7427	7435	7443	7451	745
56	7482	7490	7497	7505	7513	7520	7528	753
57	7559	7566	7574	7582	7589	7597	7604	761
58	7634	7642	7649	7657	7664	7672	7679	768
59	7709	7716	7723	7731	7738	7745	7752	776
60	7782	7789	7796	7803	7810	7818	7825	783
61	7853	7860	7868	7875	7882	7889	7896	790
62	7924	7931	7938	7945	7952	7959	7966	797
63	7993	8000	8007	8014	8021	8028	8035	804
64	8062	8069	8075	8082	8089	8096	8102	810
65	8129	8136	8142	8149	8156	8162	8169	817
66	8195	8202	8209	8215	8222	8228	8235	824
67	8261	8267	8274	8280	8287	8293	8299	830
68	8325	8331	8338	8344	8351	8357	8363	837
69	8388	8395	8401	8407	8414	8420	8426	843
70	8451	8457	8463	8470	8476	8482	8488	849
71	8513	8519	8525	8531	8537	8543	8549	855
72	8573	8579	8585	8591	8597	8603	8609	861
73	8633	8639	8645	8651	8657	8663	8669	867
74	8692	8698	8704	8710	8716	8722	8727	87
75	8751	8756	8762	8768	8774	8779	8785	879
76	8808	8814	8820	8825	8831	8837	8842	884
77	8865	8871	8876	8882	8887	8893	8899	890
78	8921	8927	8932	8938	8943	8949	8954	896
79	8976	8982	8987	8993	8998	9004	9009	90
80	9031	9036	9042	9047	9053	9058	9063	90
81	9085	9090	9096	9101	9106	9112	9117	91
82	9138	9143	9149	9154	9159	9165	9170	91
83	9191	9196	9201	9206	9212	9217	9222	92
84	9243	9248	9253	9258	9263	9269	9274	92
85	9294	9299	9304	9309	9315	9320	9325	93
86	9345	9350	9355	9360	9365	9370	9375	93
87	9395	9400	9405	9410	9415	9420	9425	94
88	9445	9450	9455	9460	9465	9469	9474	[illegible]
89	9494	9499	9504	9509	9513	9518	9523	95
90	9542	9547	9552	9557	9562	9566	9571	95
91	9590	9595	9600	9605	9609	9614	9619	96
92	9636	9643	9647	9652	9657	9661	9666	96
93	9685	9689	9694	9699	9703	9708	9713	97
94	9731	9736	9741	9745	9750	9754	9759	97
95	9777	9782	9786	9791	9795	9800	9805	98
96	9823	9827	9832	9836	9841	9845	9850	98
97	9868	9872	9877	9881	9886	9890	9894	98

eral types of feedback circuits; each is determined by
the signal that is fed back and the manner in which i
the input circuit. The feedback signal can be pro-
the load current or to the load voltage. To investi-
ous effects on circuits, we will use the block diagram
diagrams of various schematics. Further simplifica-
ned by omitting all components that are bypassed, and
ng circuits.

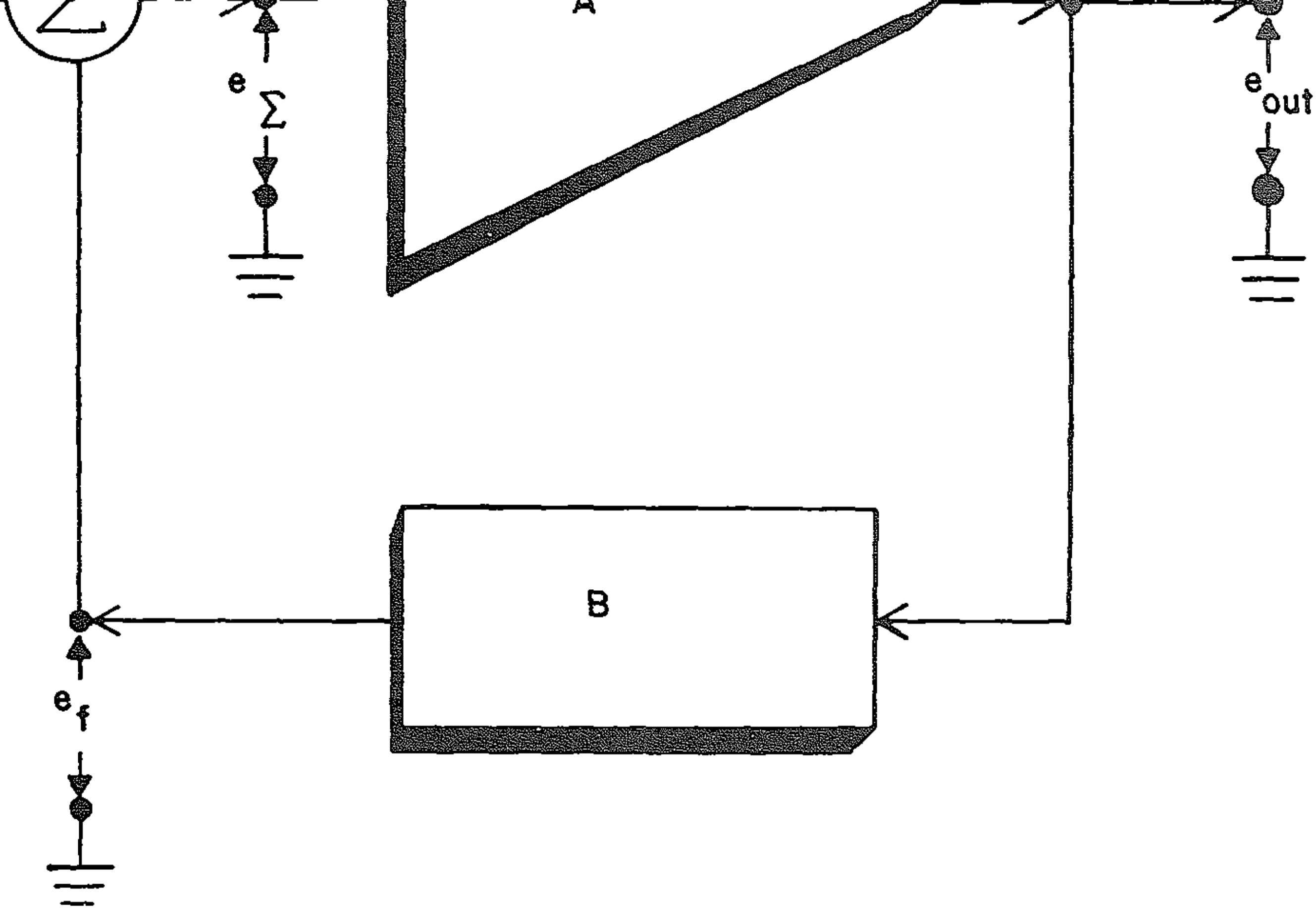
and Osterheld, Essentials of Radio-Electronics, Secon
McGraw-Hill Book Company, Inc., 1961.

c Circuits, NAVSHIPS 0967-000-0120, March 1980.



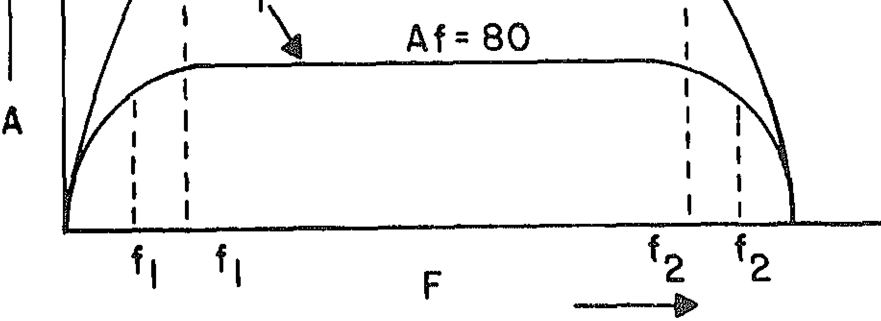
Open-Loop System

Figure 1

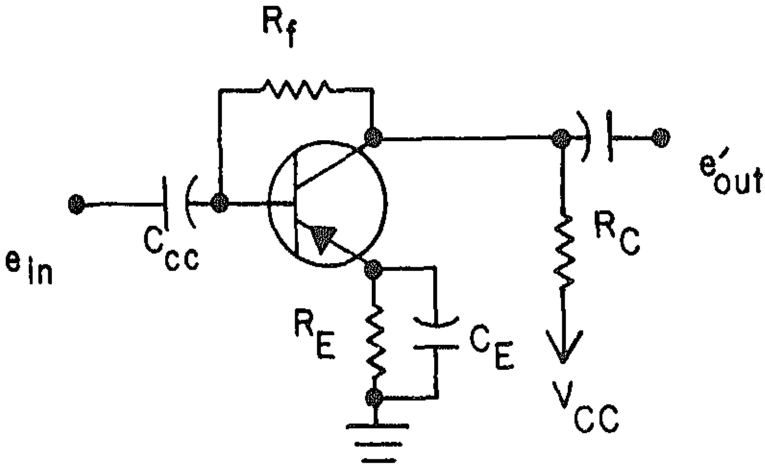


Closed-Loop System

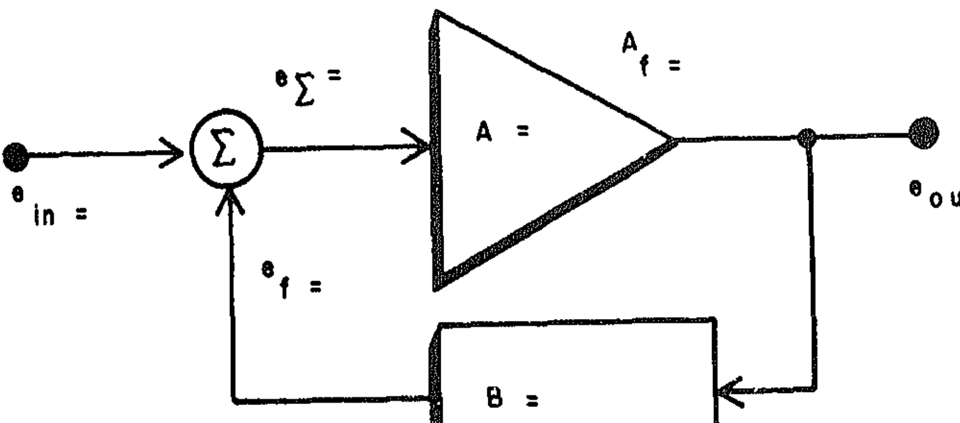
Figure 2

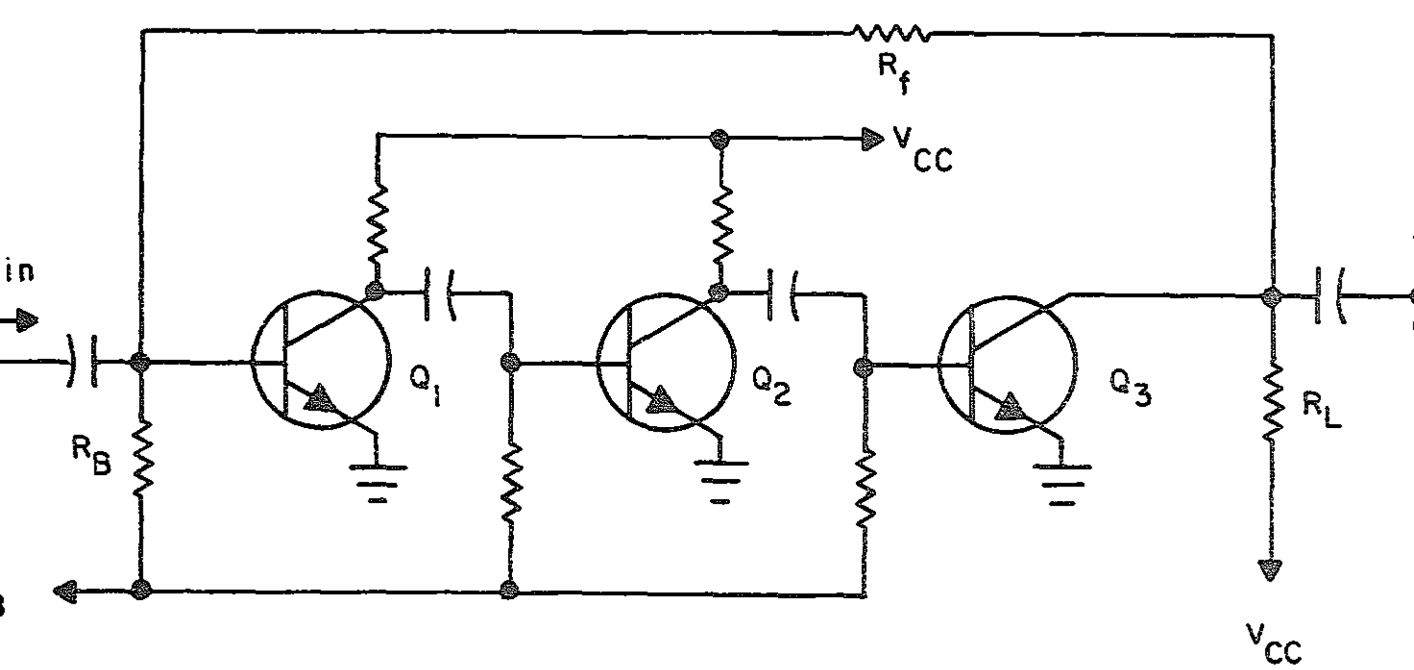


Frequency Response
Figure 3



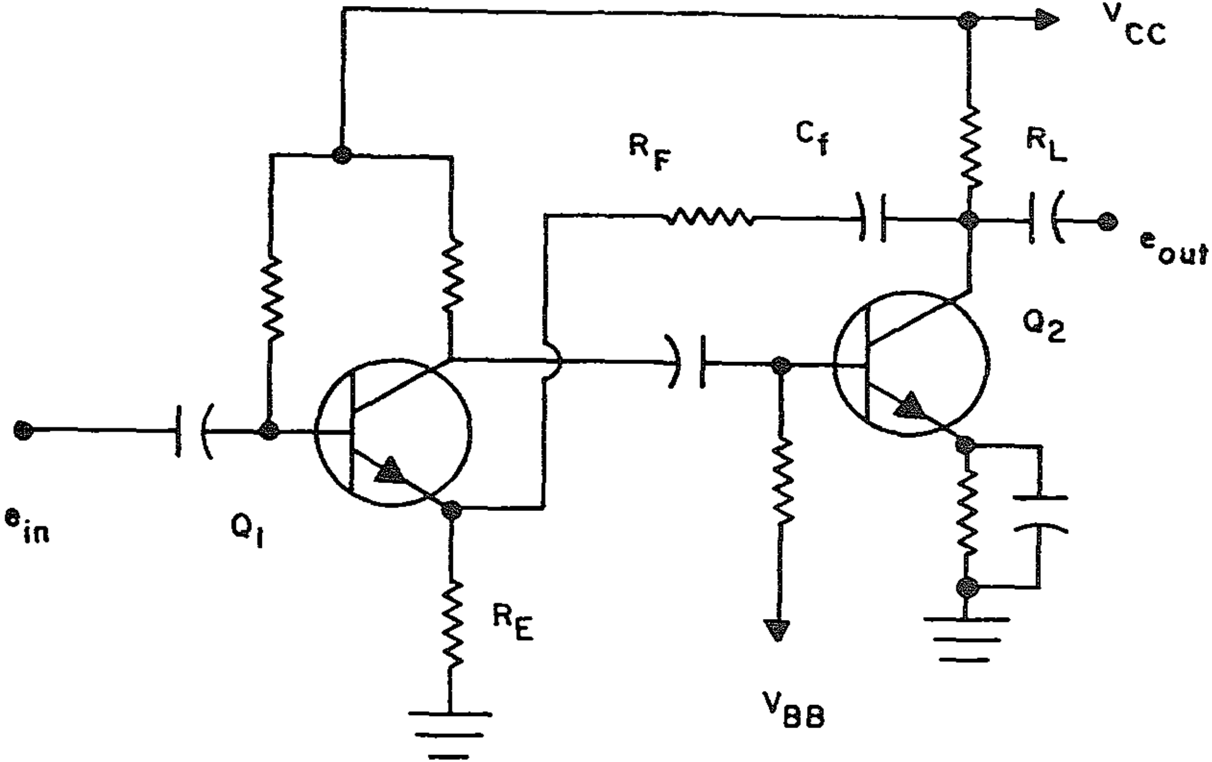
Voltage Feedback
Figure 4





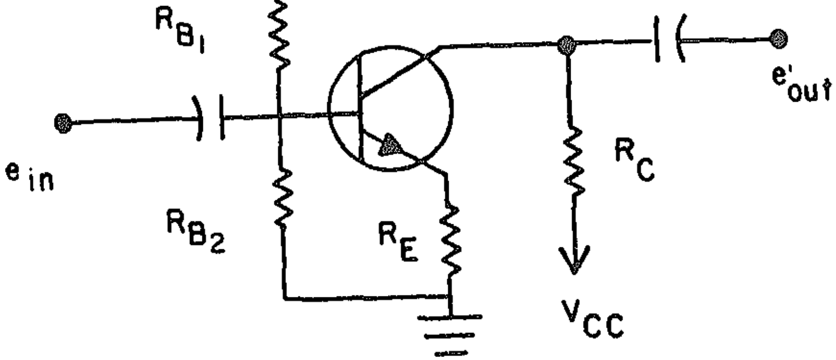
Multi-Stage Shunt-Voltage-Feedback Amplifier

Figure 6



Multi-Stage Shunt-Voltage-Feedback Amplifier

Figure 7



Current Feedback
Figure 8

Gain Formula

pen-loop system implies that no feedback path exists
tween the input/output terminals. The drive to the ga
ock (figure 1) is caused by e_{in} alone and <u>not</u> by any
rtion derived from e_{out}.

e basic gain formula is $A_v = \frac{e_{out}}{e_{in}}$. Therefore, e_{out} =
$n A_v$.

y change in A_v, causes a variation in e_{out}.

osed-loop system implies there is some form of feedbac
om the output back to the input. It is used to overco
e sensitivity of e_{out} to variation in A_v. The princip
 the closed-loop system is based on *error detection*.
presents a gain (or loss) factor introduced into e'_{out}
fore it emerges as e_f (the feedback voltage) where e'_o
 the output signal with feedback applied. β is indica
 decimal form and may be -or + to indicate whether it
 degenerative or regenerative. This will cause e_f to
 or subtract from e_{in}. Σ is the symbol of the error
tector. It will aid in developing e_Σ which is the
gebraic sum of e_{in} and e_f. $e_\Sigma = e_{in} + e_f$, where e_f =
e'_{out}. The output will follow the input quite closely
e closed-loop system. The drive to the gain block is
ried in such a manner as to hold e'_{out} relatively cons

therefore, $e'_{out} = A_v(e_{in} + \beta e'_{out})$. Multiplying th
A_v,

$e'_{out} = A_v e_{in} + A_v \beta e'_{out}$ to collect terms,

$-A_v e_{in} = -e'_{out} + A_v \beta e'_{out}$ or, as is commonly writt

$A_v e_{in} = e'_{out} - A_v \beta e'_{out}$, and

$A_v e_{in} = e'_{out}(1 - A_v \beta)$, dividing,

$$e'_{out} = \frac{A_v e_{in}}{1 - A_v \beta}$$

The closed loop gain (with feedback) is A_f.

$A_f = \dfrac{e'_{out}}{e_{in}}$ or as has been resolved previously,

$A_f = \dfrac{A_v e_{in}}{1 - A_v \beta} \div e_{in}$ which could be rewritten as

$A_f = \dfrac{A_v}{1 - A_v \beta}$ = closed-loop gain.

Negative Feedback Amplifiers

A. General

1. There are several types of feedback circuits; determined by the nature of the signal that is and the manner in which it is applied to the i circuit. Thus the feedback signal can be prop to the load current or to the load voltage.

2. The signal fed back can be applied in series c shunt with the input circuit. It, therefore, that there are four basic types of feedback ci and they are:

d. The current output-series input.

The input and output impedances of these four types of feedback circuits are affected <u>differently</u> by the applied feedback, but their individual gains will be affected <u>similarly</u> by the applied feedback.

To investigate these effects, we will use the block diagram form and basic schematic diagrams. The blocks will contain both the signal input and output leads, plus the common input and output leads for clarificatio The assumptions made are that the basic amplifier is unilateral; that is, there is no interaction between it input and output terminal pairs and the input/output impedance of the feedback network is sufficiently high ensure that it does not load the basic amplifier.

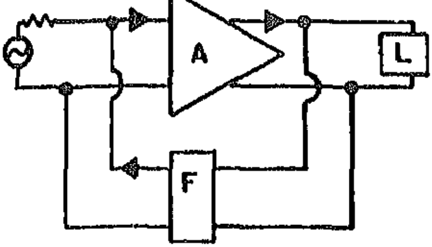
Further, simplification is obtained by omitting all com ponents that are bypassed, those capacitors with negligible reactance at mid-frequencies, and the d-c biasing circuits. The signal generator is always dis- played along with its internal resistance.

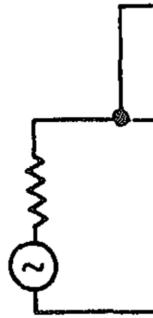
age output-shunt input

Figure 9a shows the feedback block, "F", across the loa and the input. Any change in voltage across the load i sampled and a portion of this sample is applied across, or in shunt with the input terminals. Note, in the following sections of figure 9, the feedback resistor i in series with the input resistance of the first stage.

If the feedback block is in shunt with both the input/ output terminals of the gain-block, then the input/outp resistance must be lower with this type of feedback. Also, the polarity difference between the input signal and feedback signal is 180°. The gain-block resembles constant-voltage source and is rendered insensitive to device parameter changes, relative to the amount of fee back applied.

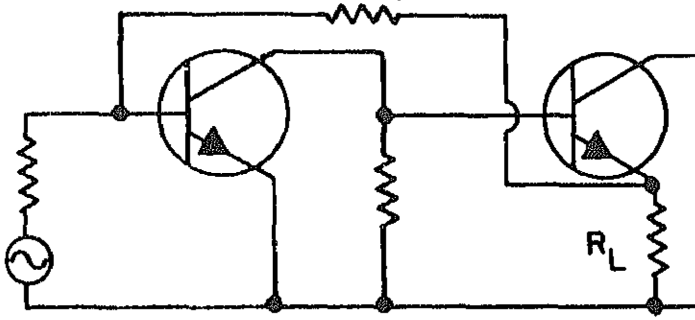
In the schematics shown, blocking capacitors would isolate the d-c voltages from upsetting the bias levels However, with careful design, the bias levels can be se



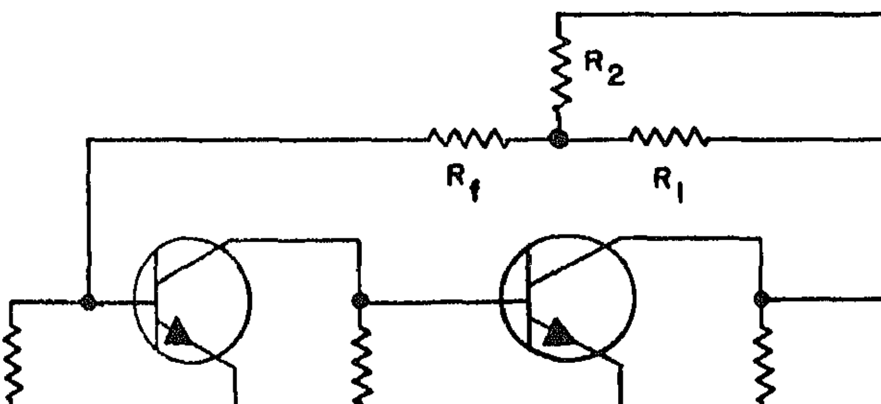


Voltage output-shunt input

(a)



(c)



e 9b represents a single stage with local feedback ed. Figure 9c is a CE to CC configuration, with the t resistance extremely low. Figure 9d shows three s of CE amplifiers. The load for the output stage . R_1 and R_2, in series, are in parallel with R_L, ne portion of the output voltage at their junction d back through R_f, which is in series with the R_i of irst stage.

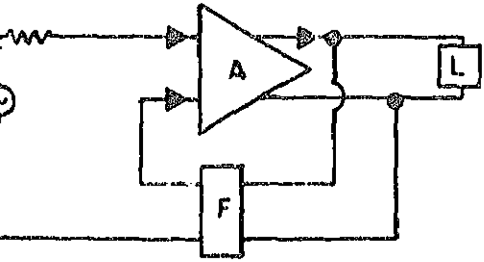
l the cited cases, the input driving signal has been tively reduced, reducing the output signal. Both nput and output resistances are lowered. Bandwidth creased, distortion reduced, stability increased, eriodic noise reduced.

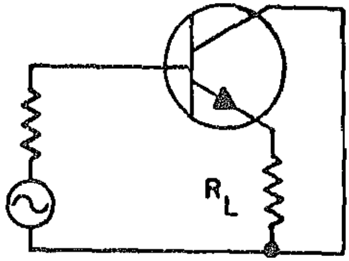
utput-series input

e 10a is the block diagram of this feedback arrange- The voltage across the load is sampled and a on of it, called the feedback voltage, is applied in s with the input signal. The polarity of the feed- signal is such that it will oppose the input signal, ing the effective drive to the gain-block.

e 10b shows the extreme case of 100% voltage feed- in an emitter follower or CC amplifier. Reasoning ls that this could not be 100% degeneration, or else would be no output. The only way to cause 100% eration would be to throw the power "on/off" switch e "off" position.

e 10c shows two CE amplifiers and figure 10d has an CC stage to effect a much lower output resistance. l cases shown so far, the output circuits are ed by the feedback circuits, lowering the output tances and keeping the output signals constant, with tions in the gain-block. However, in figure 10, the ack voltage is applied in series with the input l, thus greatly reducing the input driving signal nt. This has the effect of increasing the input tance. The polarity of the feedback signal is in with the input signal and opposes its action. fore, the input resistance is increased while the t resistance is lowered. With this application of

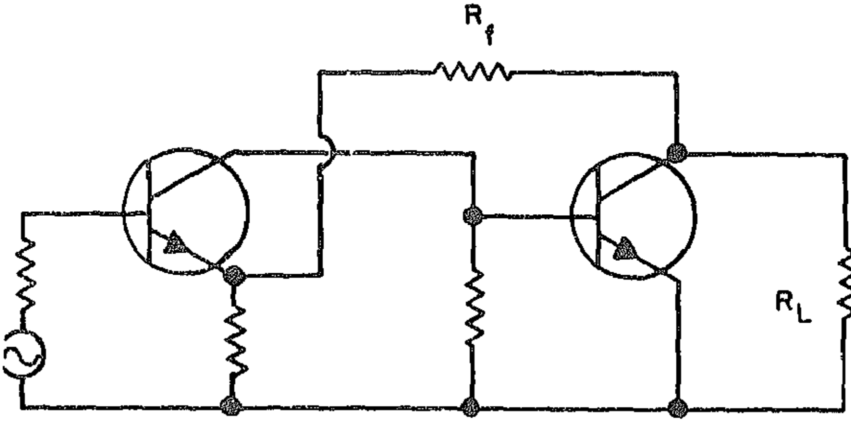




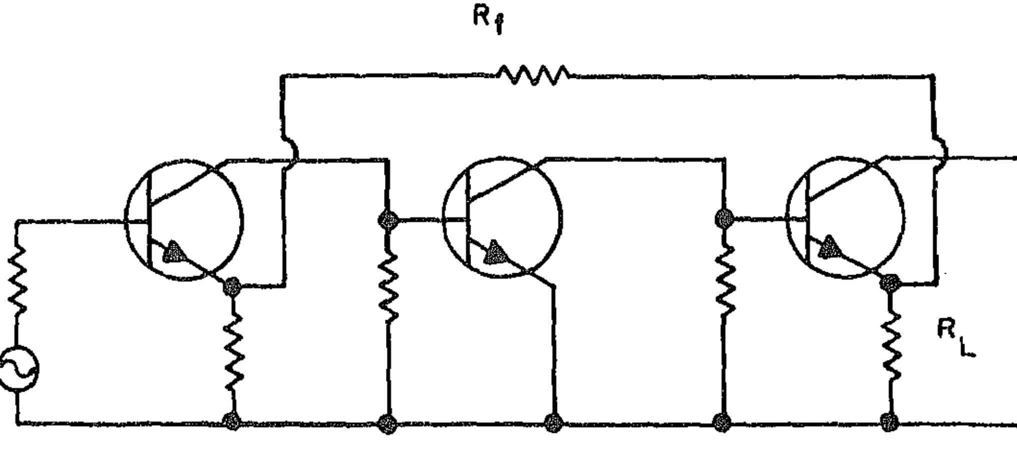
tage output-series input

(a)

(b)



(c)



lock.

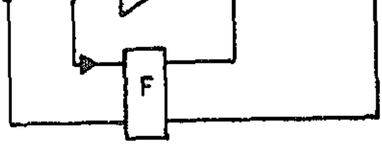
igure 11b shows a CE to CE amplifier with the output esistance being increased and the input resistance b owered by this type of feedback. The feedback signa aken from R_1, which samples the output load current. s then applied through R_f in series with the R_i of t irst stage. Since this type of feedback tends to ke he output current constant, the gain-block resembles onstant-current generator with its high output esistance.

n figure 11c, R_2 samples the load current and is als art of the load resistance of the last stage. Load-urrent variations develop the feedback signal voltag cross R_1. The gain, stability, distortion, and nois his type of feedback application are similar to the thers discussed.

nt output-series input

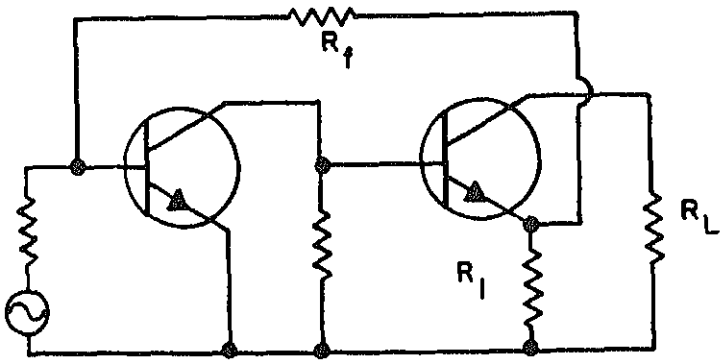
igure 12a shows a block diagram with the output load urrent flowing through the feedback sampling circuit nd the feedback voltage developed by the load curren hich is applied in series with the input signal.

his application maintains a constant output current reatly controls the input driving signal current. T nput and output resistances are increased by this ty eedback application. Figure 12b shows the CE amplif ith the resistor in the emitter leg. It is strongly mphasized here that this resistor will prevent therm unaway. Reasoning reveals that if the output curren ends to "run", the feedback voltage it develops acro educes the forward bias, resulting in slowing the "r o a "crawl" and a "stand still." This resistor, whe ypassed, allows maximum stage gain. However, when nbypassed, it introduces degenerative feed-back to t pplied a-c signal and improves the stability, bandwi istortion, and noise figure as discussed previously.

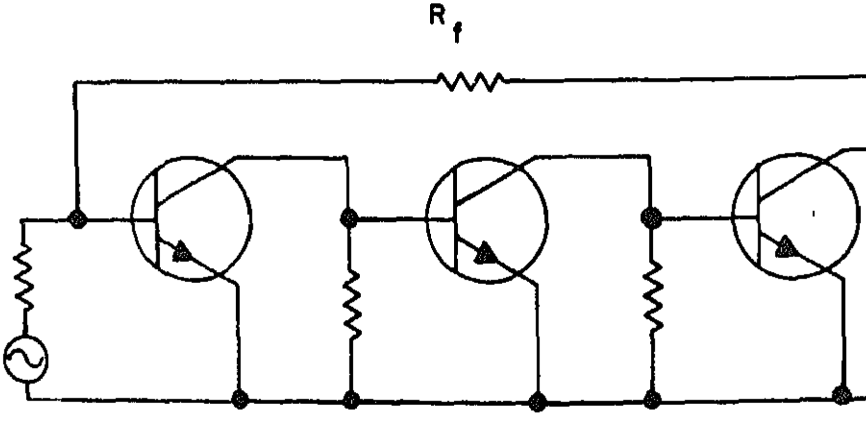


Current output-shunt input

(a)



(b)



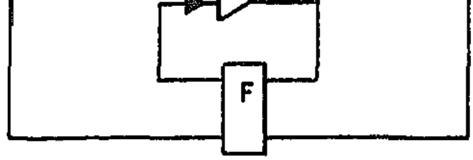
(c)

al feedback

ng on the requirements, feedback can alter slightly tically, the input/output resistance of any type of er. The characteristics of one can be overshadowed ner, depending on the amount of each applied.

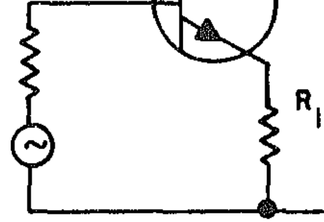
10c is voltage output-series input, but the emitter first stage introduces a small amount of current series input, locally. This, of course, is able, because the emitter of the first stage must e ground for injection of the overall feedback The same holds true for figure 10d.

plexities which reactive components add to feedback great to be analyzed in this allotted time. The ian will see various types and applicatons during ubleshooting procedures. With experience and studies, you will become familiar with the forever feedback circuits.

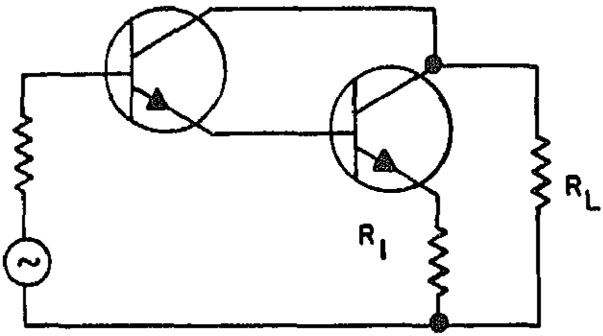


urrent output-series input

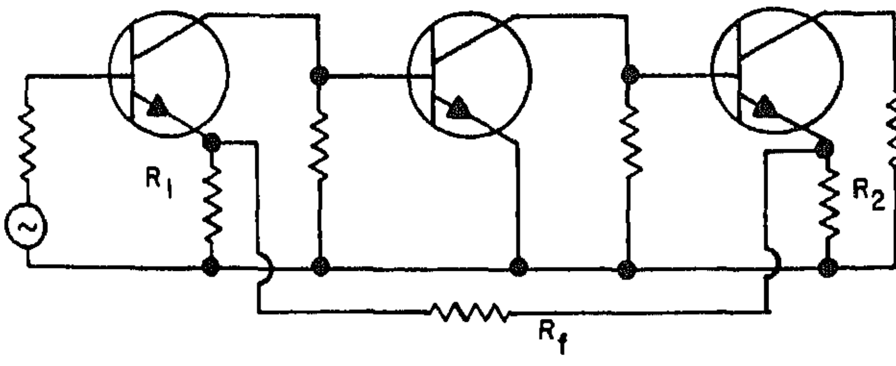
(a)



(b)



(c)



s of Radio-Electronics, Slurzburg & Osterheld, McGraw-
Second Edition, 1961.

c Circuits, NAVSHIPS 0967-000-0120, March 1980.

TLINE:

pen-Loop System

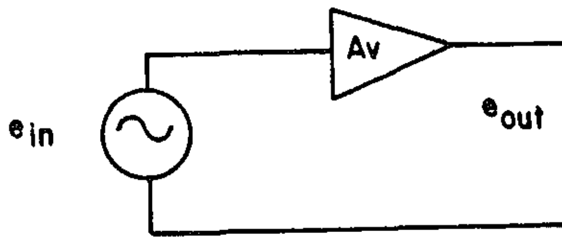
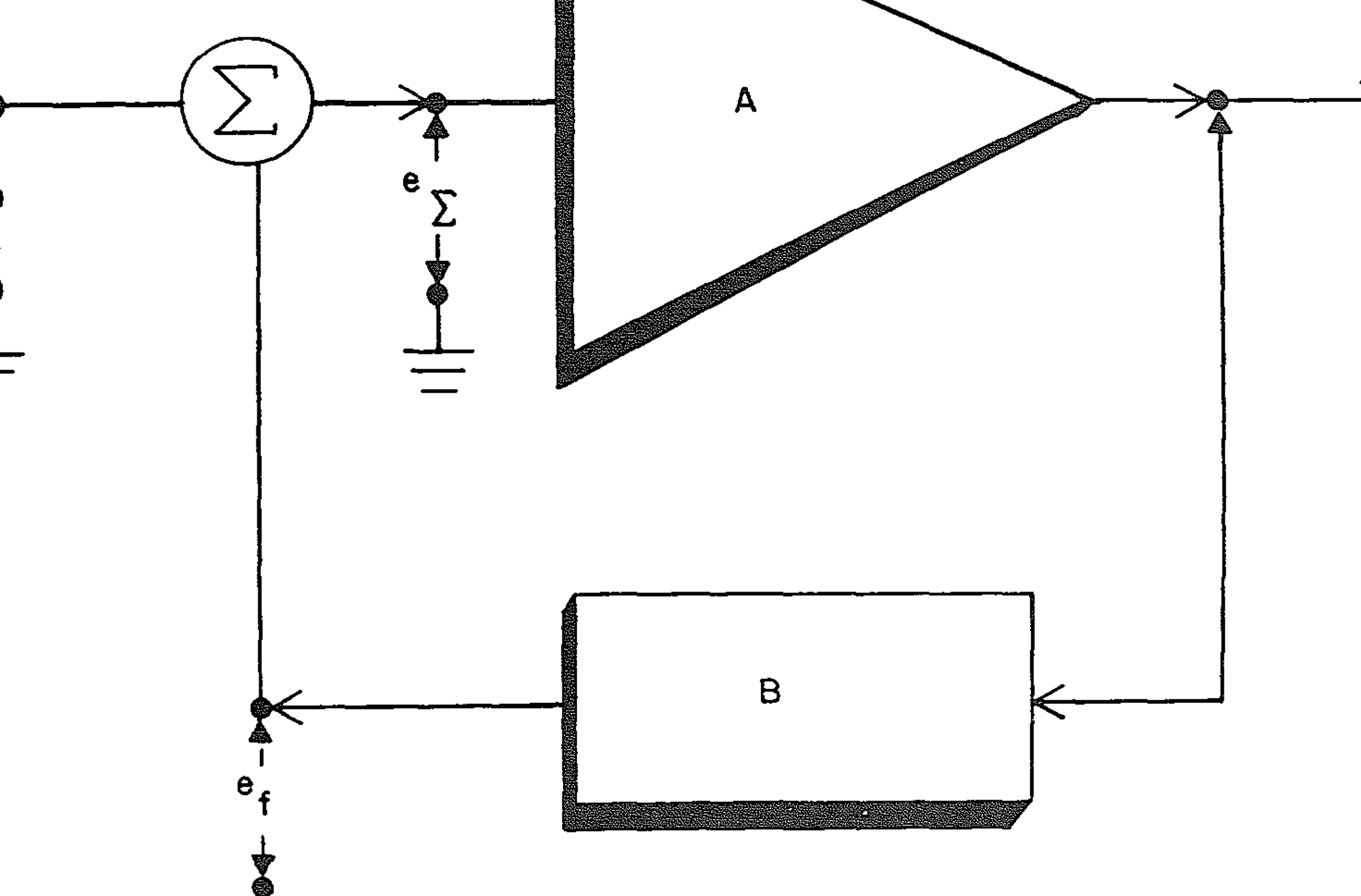


Figure 1

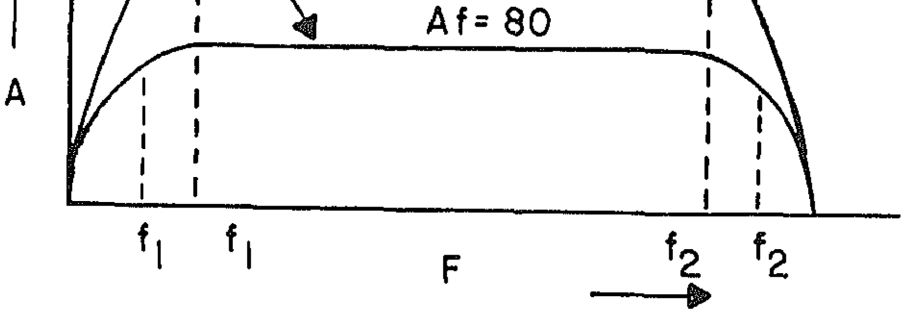


Closed-Loop System

Figure 2

III. Classes and Types of Feedback

Characteristics



Frequency Response
Figure 3

. Transistor Circuits

A. Single stage voltage feedback

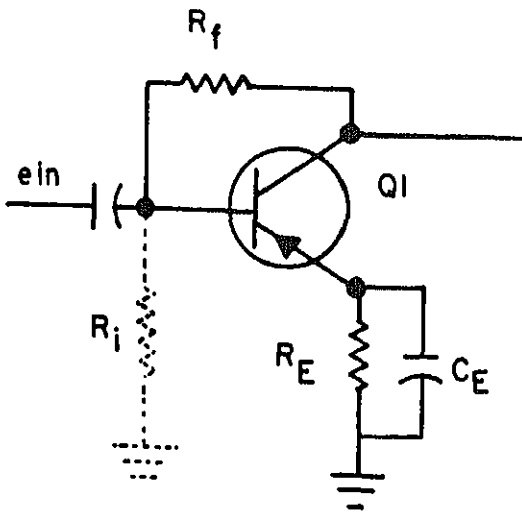
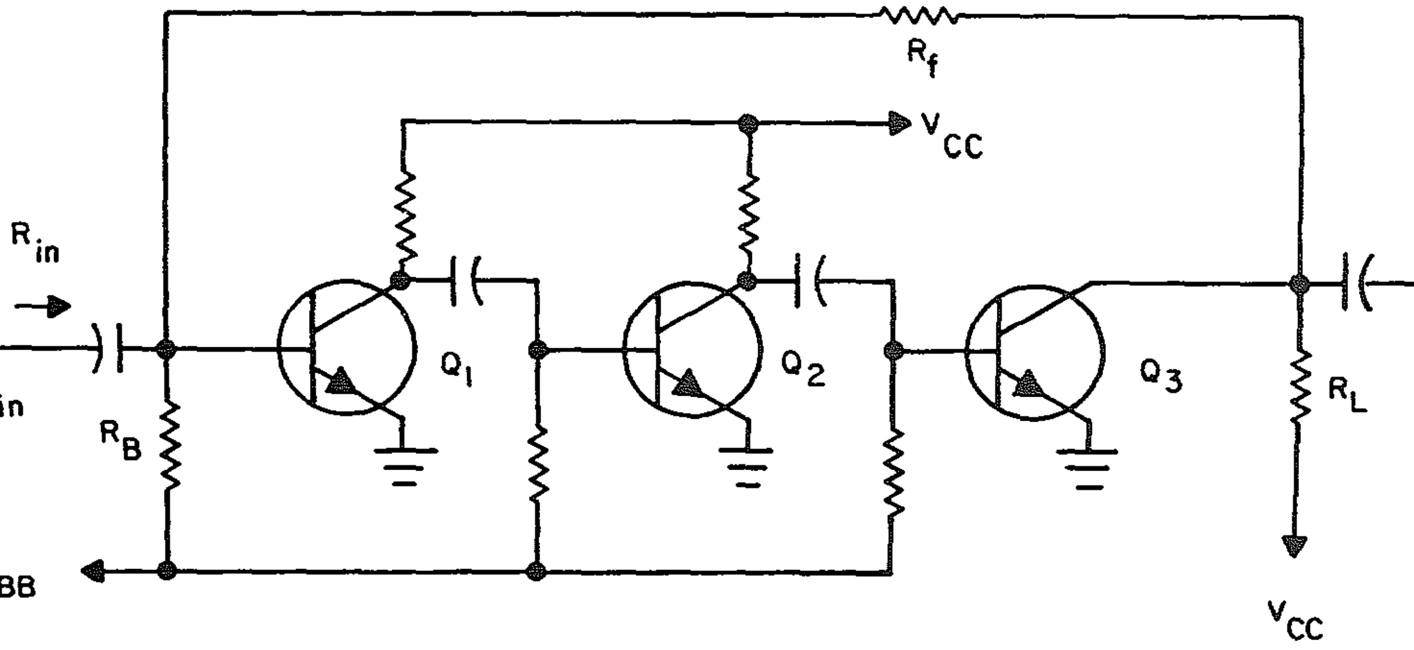


Figure 4 - Single-Stage-V
Feedback.

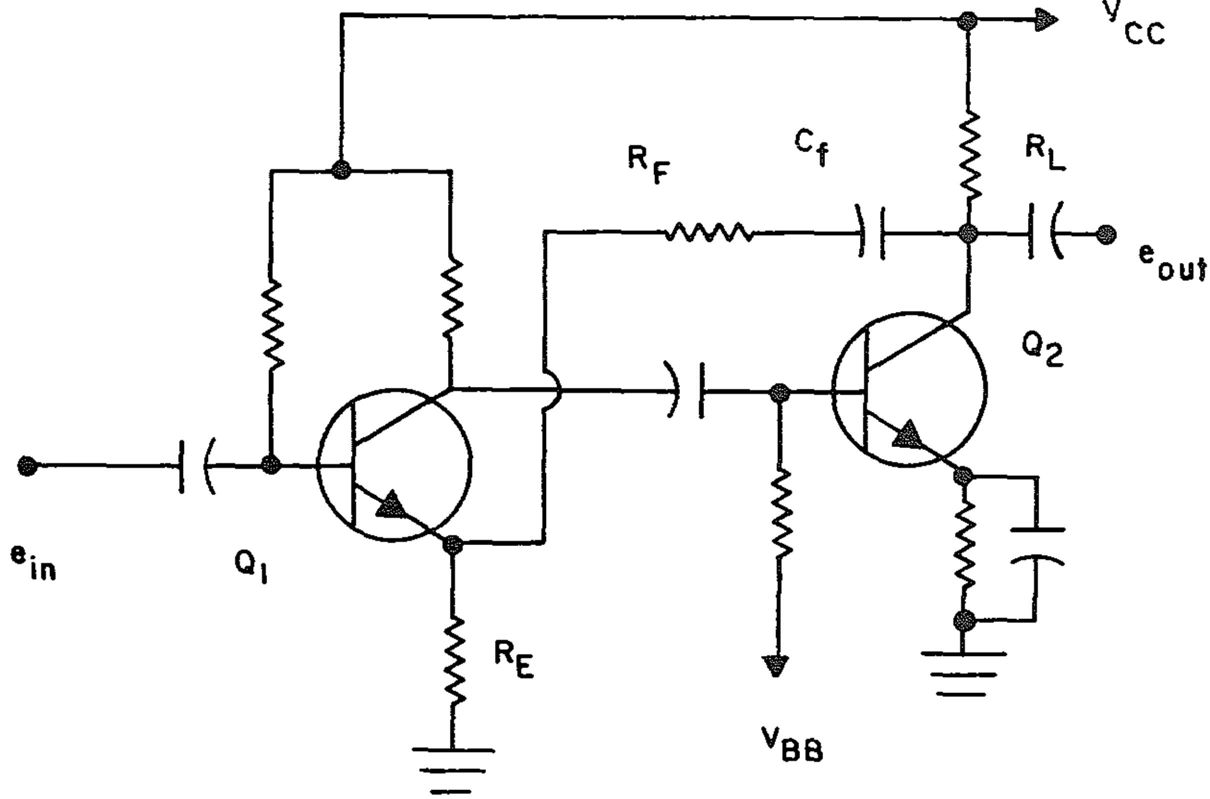
C. Multistage voltage feedback (series)



Multistage Shunt-Voltage-Feedback Amplifier

Figure 5

D. Current feedback



Multistage Series-Voltage-Feedback Amplifier

Figure 6

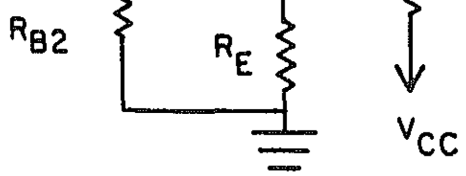


Figure 7 - Current Fee

E. Combination feedback

n systems, require the amplification of d-c voltages stage of amplification is not sufficient to bring of such signals to the required values; therefore, types of coupling are necessary to ensure that maxice of energy is required. This lesson on direct perational amplifiers is essential for the

Kiver, Transistor and Integrated Electronics. l Book Company, Fourth Edition, 1972.

Shrader, Electronic Communication, McGraw-Hill Book ourth Edition, 1980.

ing figures are labeled by title and will assist you ng the instructor through the lesson.

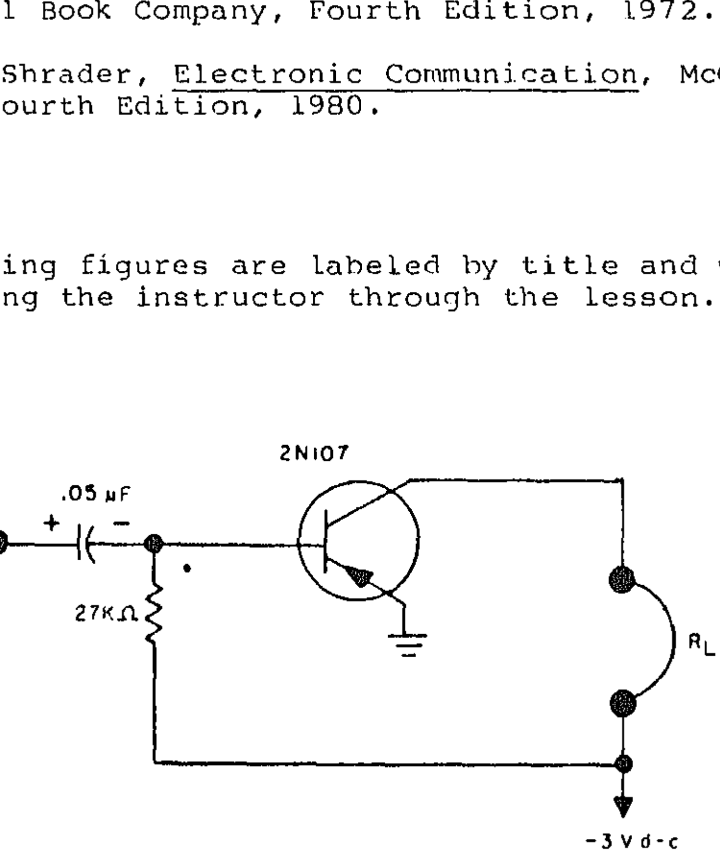


Figure 1

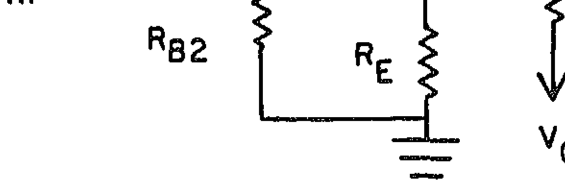


Figure 7 - Current

E. Combination feedback

onic systems, ranging from voltage regulators to compl
tion systems, require the amplification of d-c voltage
one stage of amplification is not sufficient to bring
de of such signals to the required values; therefore,
nt types of coupling are necessary to ensure that maxi
rence of energy is required. This lesson on direct
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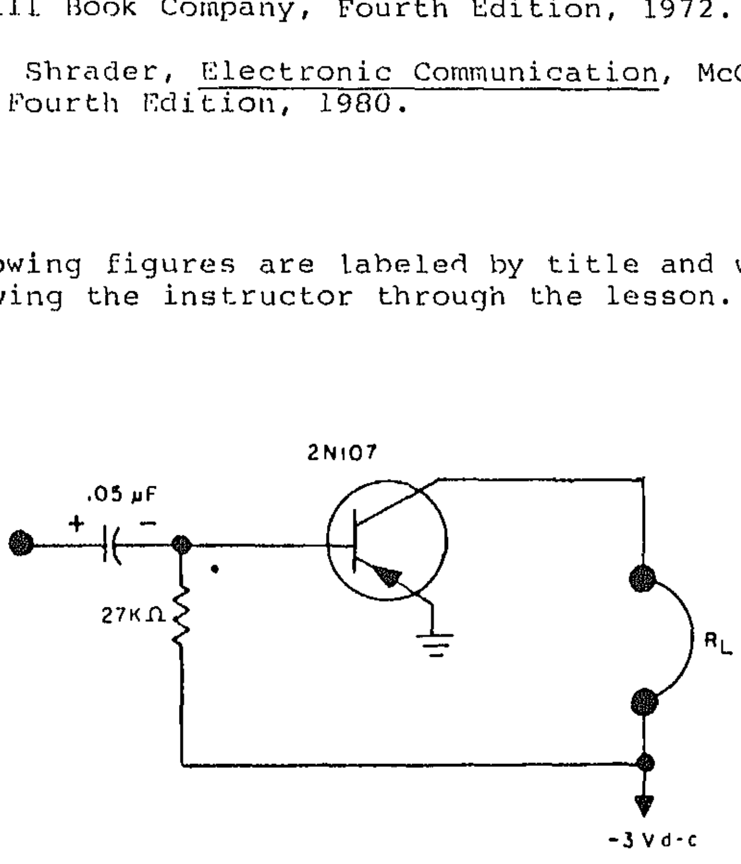
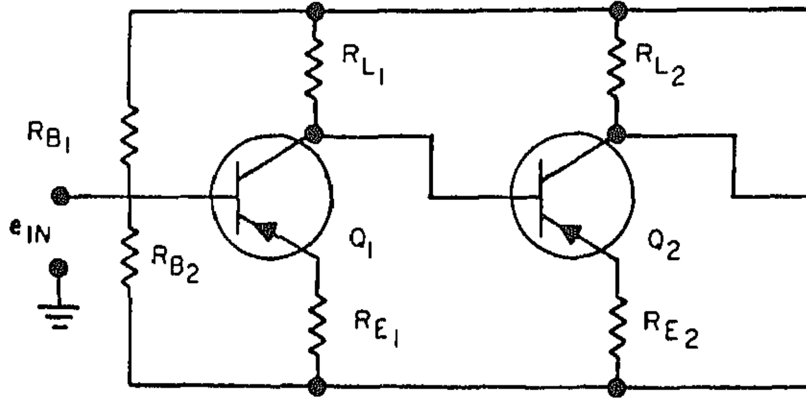
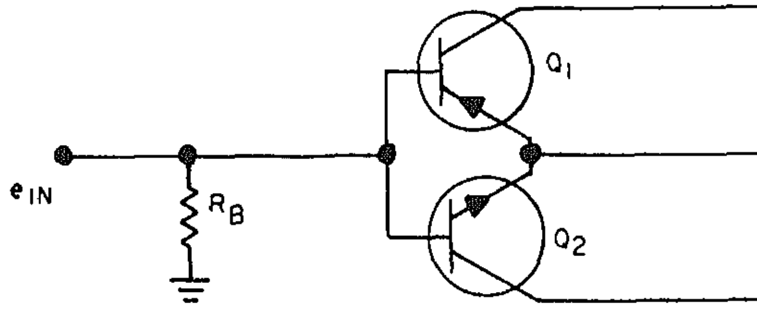




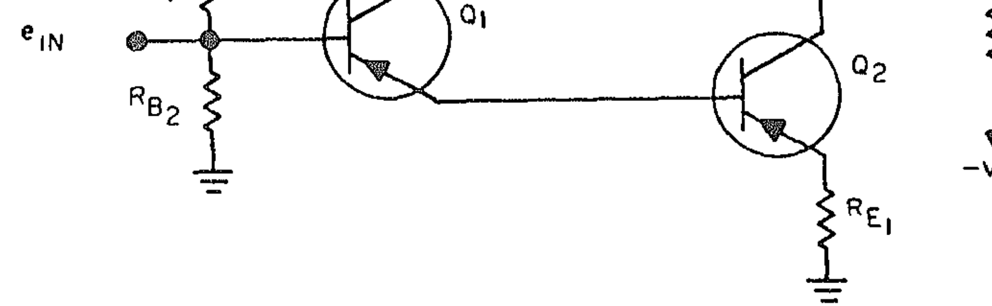
Cascaded CE d-c Amplifier.

Figure 2



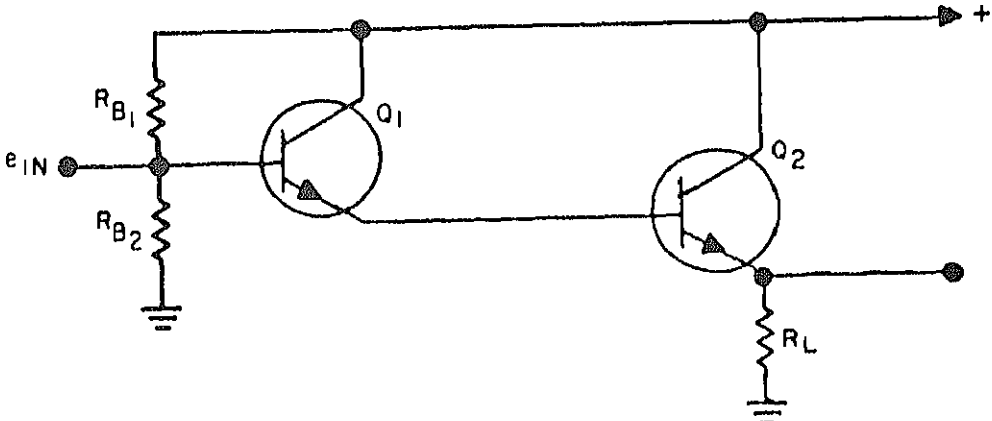
Complementary Symmetry

Figure 3



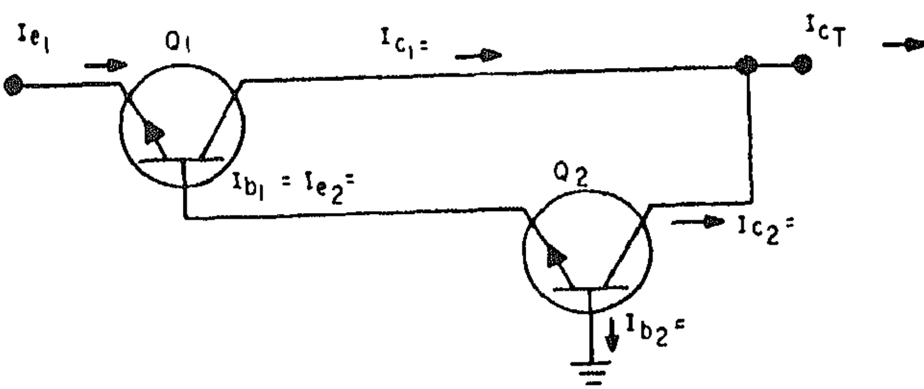
Compound-Connected

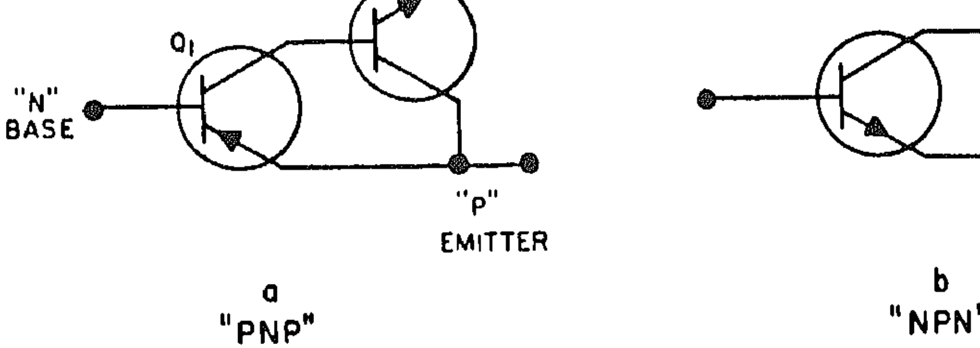
Figure 4



Darlington Circuit.

Figure 5





Complementary Darlington's

Figure 7

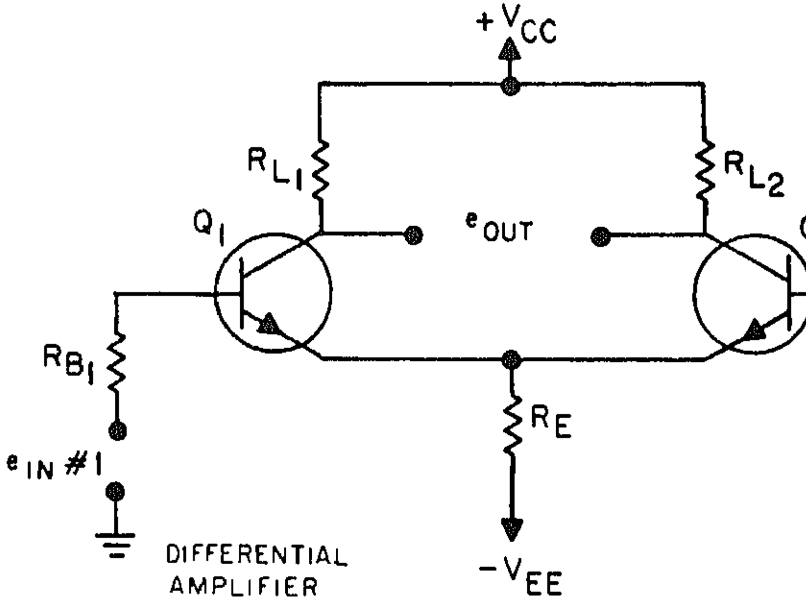


Figure 8--Modulated a-c Carrier

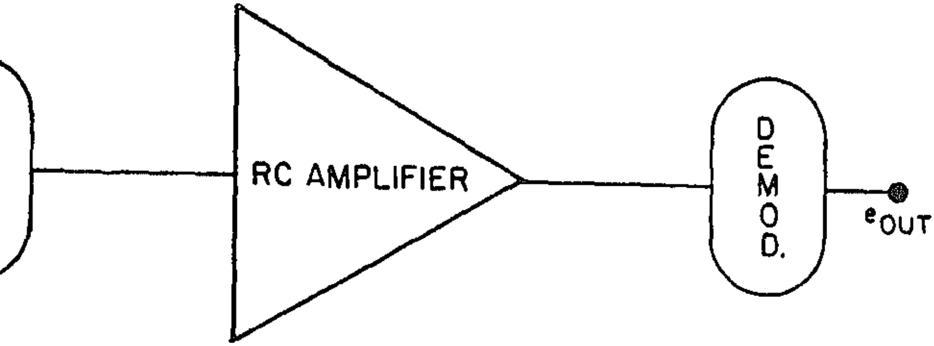


Figure 9--Chopper Amplifier

ED AUDIO AMPLIFIER

ion

ct-coupled audio amplifier is used where high gain udio frequencies or amplification of direct (zero frequency) is desired. The direct-coupled plifier is also used where it is desired to e loss of frequencies through a coupling network. cuit has numerous applications, particularly in s, measuring or test instruments, and industrial equipment.

ristics

common-emitter circuit for high gain.

lly requires thermal stabilization to prevent way.

uency response extends to zero frequency (direct ent).

onds equally well to pulses or sine waveforms.

Analysis

is also applied to another element. No p
or decrease is self-correcting in the fol
sistor. In most instances, however, the
becomes a major problem if more than two
amplification are cascaded.

2. Germanium transistors are more subject t
instability than are silicon transistors
case it is usually necessary to provide
temperature compensation if the temperatu
centigrade. The complexity of the compe
cuitry is dependent upon the amount of c
Because of the rapid changes which are o
semiconductor field, it is likely that t
pensation will be eliminated or minimize
degree in the future. Even so, however,
limitaion of direct coupling still remai
necessity for cumulatively increasing th
operating values as each stage is cascad
use of low bias and collector voltages p
more range than can be obtained with the
the transistor, like the electron tube,
maximum breakdown or reverse potential l

3. In addition, noise is a problem, since t
amplifies any internal noise as well as
transistors are prone to produce greater
lower audio frequencies. Thus, the abil
amplifier to extend its response to low
normally available through other couplin
somewhat nullified by the amplification
noise in the transistor. Generally spea
the low-frequency response of the d-c am
limited only by the signal-to-noise rati
high-frequency response is limited by th
response characteristics of the transist

4. In the direct-coupled amplifier, the col
input stage is directly connected to the
second amplifier stage; therefore, any c
variation also appears at the base of th
just as if it were a change in the input
the transistor in the second stage has n
criminating between actual input signal

e an output signal. Similarly, a change in
in any stage or on any element will be
proportionally, and a change of output will
h changes in bias levels normally occur as a
emperature variations, aging, difference in
characteristic due to manufacturing
or changes in transistor leakage current, and
d to as drift.

on of the forward-bias characteristics of a
manium diode with temperature is shown in
The forward-bias variation is usually
s a change in bias voltage with temperature
nt forward-bias current. It is usually
becomes significant because of the large
on it receives because of the direct-coupling
.

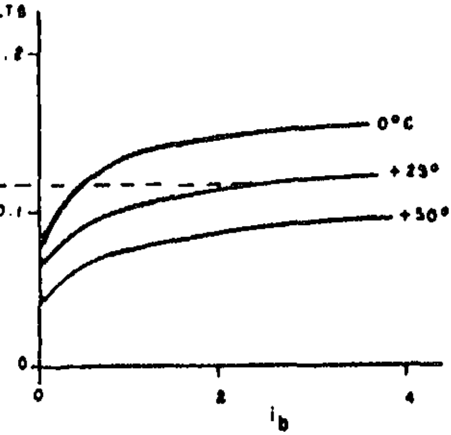
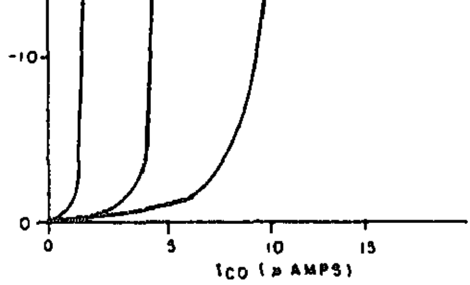


Figure 10

ner in which the collector-base diode varies
verse saturation current with temperature is
own in figure 11 (for a typical germanium
stor). In this instance, the figure shows
e reverse-current characteristic is highly
ture-dependent, and relatively large current
ons are produced as the temperature is



VARIATION OF COLLECTOR-BASE DIODE REVERSE CURRENT

Figure 11

8. In a similar manner, it can be shown that current transfer characteristic of a germ sistor also varies with temperature; howe case the gain can either increase or decr temperature (silicon types generally incr temperature). The percentage variation i temperature varies greatly with the opera many units show a change in sign as well The gain variation of a silicon type may ten times that of a germanium type. Thus, that the major sources of drift in transi changes in the d-c properties of the coll emitter-base diodes, and changes in the c transfer ratio. Generally speaking, in c operation and performance of germanium ar transistors, it can be said that at tempe that of the reference temperature, T_O, th comparable. At and above the reference t silicon type tends to have lower drift. temperature for silicon is 100° centigrac germanium is 60° centigrade. With low sc ance, low values of drift are obtained ab with high source resistance, the best pe at temperatures where the reverse-satura current may be neglected.

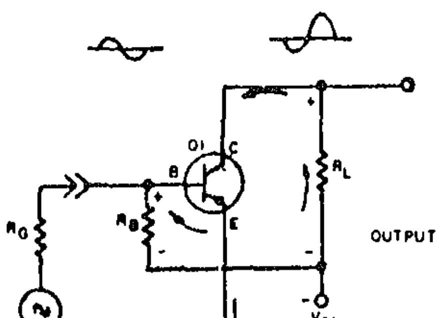
9. In d-c amplifiers, low drift is obtained with low values of collector current; th reverse-leakage current by keeping the v the collector and the base at a low valu is a forward bias for reverse current.

s somewhat limited. In single-ended amplifier stages, oth the current drift and the voltage drift in the econd stage tend to help cancel the input-stage drift; n a differential d-c amplifier, however, the drift in he second stage may either aid or oppose that of stage , depending upon the design.

espite the apparent disadvantages of the d-c amplifier t does produce (for a two-or three-stage unit) high ain and good fidelity, particularly in the low- requency portion of the spectrum. It also provides mplification with as few parts as possible; thus, it i conomical to build. In actual practice, the d-c mplifier is usually limited to one or two stages of mplification because of drift, especially where d-c ust be amplified or where frequencies of 10 to 12 Hz re of importance. To overcome the effects of drift in -c amplifiers, a special "chopper amplifier" has been eveloped; this amplifier converts the d-c into a-c so hat the stages can be isolated and thus prevent the umulative drift which normally occurs. This is a pecial type of amplifier, which will be discussed late n this section of the Information Sheet.

it Operation

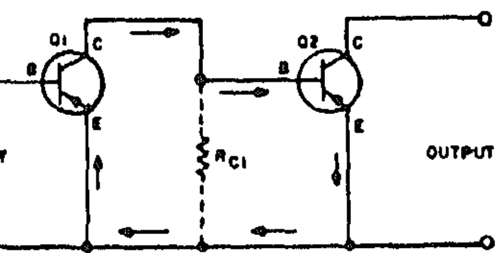
asic Circuit. The schematic of a basic common-emitter -c amplifier is shown in figure 12. the input signal s represented by the AF generator with an internal esistance equal to R_{INT}. The input signal is applied etween base and emitter. Transistor Q_1 is biased by



opposes the bias between base and emitter,
normally chosen for class A operation. Th
electron current flow through the collecto
resistor, R_L, is indicated by the arrows.
of the resulting d-c voltage across the lo
is as shown. When the positive alternatio
signal is applied to the base, the base-to
is reduced (since the signal and bias volt
opposite polarity). Because the base-to-e
tial is now less than the normal value, th
from the emitter to the collector is lower
electron flow through the output load resi
reduced. The decrease in voltage drop acr
duces a negative swing and, consequently,
negative output signal across R_L. As the
input signal goes negative, the bias poten
by the input signals, and as the base-to-e
is increased, more hole current flows to t
This produces more electron flow through t
circuit, increasing the voltage drop acros
produces a positive output-signal swing du
that the input signal is negative. This e
produces an opposite-polarity output signa
referred to as a 180° phase reversal). Si
load for both d-c and a-c, there is only c
line, and any internal noise voltages flow
the load resistor add to the developed out
Since the output across R_L is applied dire
base of the next stage, it can be seen tha
components appear across the following inp
In an a-c coupled circuit, these noise com
sisting of d-c or very low frequencies, ar
eliminated (blocked by the coupling capaci
noise components are produced by thermal e
also result from electron flow through the
resistor. They include the so-called <u>whit</u>
generated by diffusion-recombination effec
transistor (similar to shot noise in the e
and surface and leakage noise from the tra
is sometimes referred to as <u>semiconductor</u>
to distinguish it from white noise. Such
mostly confined to the region of from 1 to
white noise (in the audio range), with the
noise predominating and increasing for fre
than 1 kHz. The d-c noise results from su

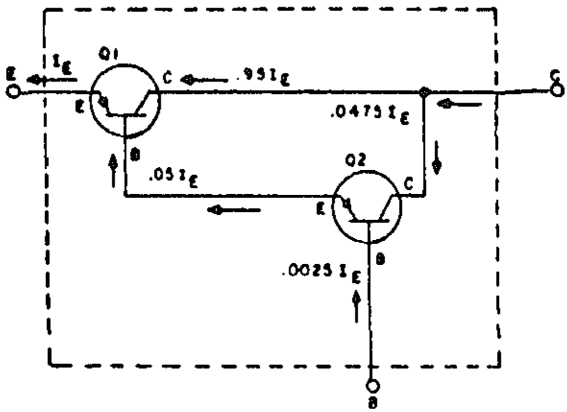
ner hand, with proper input and output match-
num gain is obtained in the stage; moreover,
oupling network to create a loss between
ximum output and efficiency are produced.
frequencies are present, including d-c (zero
and are applied equally to the next stage, it
lerstood why the d-c amplifier presents maximum
excellent frequency response, particularly at
frequencies.

Stages. Because of the high gain possible per
ny applications require only a single stage of
ed amplification. Where more than one stage is
transistors offer circuit arrangements that
ossible with electron tubes. For example,
ne use of complementary symmetry, it is
to connect the collector of the input stage
to the input of the second stage without dis-
as arrangements, and to use the same supply.
alternate arrangements of NPN and PNP tran-
only one supply is needed. Recall that in the
be d-c amplifier, as each stage progresses, the
tage is increased, with the grid being tapped
the preceding-stage plate voltage to obtain
Only tandem arrangements of similar-type
rs can follow this principle. The term comple-
ymmetry is derived from the fact that the NPN
r is the complement of the PNP transistor, with
uits operating identically, but with opposite
s. Figure 13 shows a simple direct-coupling
sing complementary symmetry.



this resistor is not needed and proper
saving in components. To do this, of c
sistors must be of opposite types (NPN

4. By the use of a special compounding con transistors may be employed as a specia amplifier to obtain linearity and almos (alpha). Figure 14 shows the compound connection, using the common-base confi



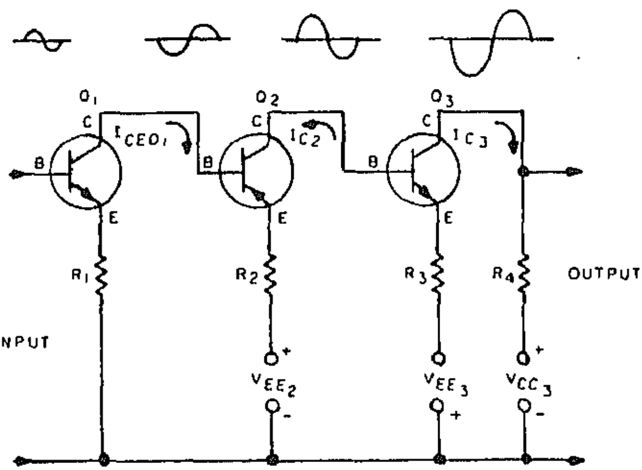
COMPOUND CONNECTION

Figure 14

Note that the input to the second stage current of the first stage. Effectivel impedance is the series combination of sistors, while the outputs are in paral circuit is roughly analogous to the pus tube circuit. Actually, this circuit i single-transistor compounded-type circu base, and collector resistors used exte direction and relative values of curren in the figure, assuming the use of two an equal a_{fb} of .95. When these values to a_{fe}, the total combination value (.9 a gain of 399 as compared with a_{fe} of 1 transistor, or more than the normal gai in cascade (19 x 19 - 381). Compounded

an amplifier, or are used as the d-c amplifier in a tage-regulator circuit.

ypical three-stage, single-ended d-c amplifier is wn in figure 15. It represents the minimum of parts d-c supplies needed for a high-gain, three-stage plementary-symmetry type of d-c amplifier for small nal applications.



TYPICAL THREE-STAG AMPLIFIER

Figure 15

shown, the base of the input stage is completed ough the input device, it is effectively open, it has driving voltage, and zero base current exists. The lector current, I_{CEO_1}, flows through the base of ge 2, which is biased by supply V_{EE_2} in series with emitter of stage 2. Since stage 1 uses a NPN trantor, the positive emitter bias of stage 2 is of the per polarity to act as collector voltage for Q1. Any nge in the collector current of stage 1 appears at collector of stage 2 in amplified form; that is, $= B_2 I_{CEO1}$, where B_2 is the current gain of stage 2. ge 2 uses a PNP transistor; therefore, by conpletary symmetry, stage 3 must also be an NPN stage

act as emitter-swamping resistors to help
amplifier with respect to temperature var

Assuming that the input stage has a colle
5 μA and assuming a gain of 38, the secon
have a collector current of 190 μA. With
the third stage collector current will be
clear that any slight change in the curre
caused by temperature or noise will be gr
and appear at the output of stage 3. Wit
tivity and amplification, therefore, it i
mandatory that such an amplifier be tempe
compensated, even if room temperatures do
excessively. Naturally, the amplitude of
signal must be limited if true fidelity i
obtained. Driving the transistor into cu
saturation would clip the peaks of the si
an electron-tube operation. It is also e
low-noise transitors must be used; otherw
might mask the signal. Note that in this
small emitter bias of stage 2operates as
voltage of stage 1. Low collector voltag
minimize noise generated in the input sta

ional amplifier is an extremely efficient and device. Its applications span the broad electronic illing requirements for analog instrumentation, putation, and special system design.

, the term "Operational Amplifier" was used in to describe amplifiers that performed various al operations. It was found that the amplification e feedback around a high gain d-c ampifier would circuit with precise gain characteristics that nly on the type and amount of feedback used. By the ection of feedback components, operational amplifier ould be used to add, subtract, multiply, divide, and differentiate.

al amplifier techniques became more widely known, it nt that these feedback techniques could be used in ol and instrumentation applications. Today, the e of operational amplifiers has been extended to ch applications as d-c amplifiers, a-c amplifiers, s, servoamplifier, deflection yoke drivers, and a ners.

perational amplifier can do is limited only by the n and ingenuity of the user. With a good working of its characteristics, you will be able to exploit the useful properties of operational amplifiers.

<u>Integrated Electronics</u>, Kiver, McGraw-Hill, Fourth pages 271-305

- An operational amplifier is a high gain, direct- -c) amplifier utilizing degenerative feedback for its amplification factor.

than one, then the operational amplifier is d
For example, an amplifier with a gain of .5 w
multiply its input by 1/2.

2. Gain itself is determined by the ratio of inp
output voltage.

$A = \frac{E_o}{E_{in}}$. The voltage gain of an operational
a ratio of $E_o : E_{in}$.

3. However, the amplifiers do improve the perfor
various computing loops, by accomplishing the
reversing the sign of a voltage with or witho
scale factor; isolate or eliminate the loadin
puting element from another; provide a voltag
to the algebraic sum of two or more input vol
the various functions performed by operationa
they are called by several names; computing a
isolation amplifier, feedback amplifier, and
amplifier.

C. Functional analysis

1. Amplifier section

a. In order to better understand operational
we will first go through the different po
operational amplifier.

b. The heart of the operational amplifier is
section. It is represented by the triang
1. It contains an odd number of direct-c
amplifiers, usually three or five stages.
number of amplifiers are required to prov
grees of phase shift from input to output
voltage will always be oppostie or invert
respect to the input polarity to provide
feedback.

c. Open loop gain, that is the gain of the a
without feedback, is from 1×10^3 to 2 x
usually around 50×10^3 or 50 k; 92 dB.

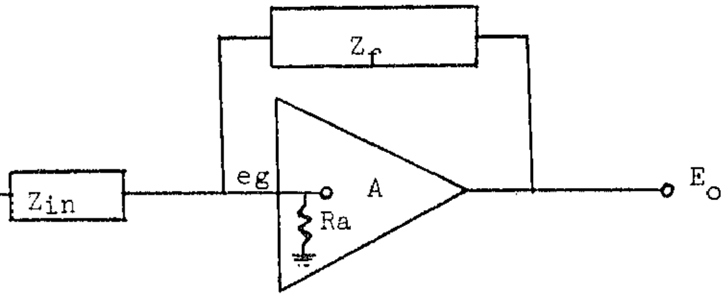


Figure 1

igure 2, is an expanded view of the amplifier
ion in block diagram form.

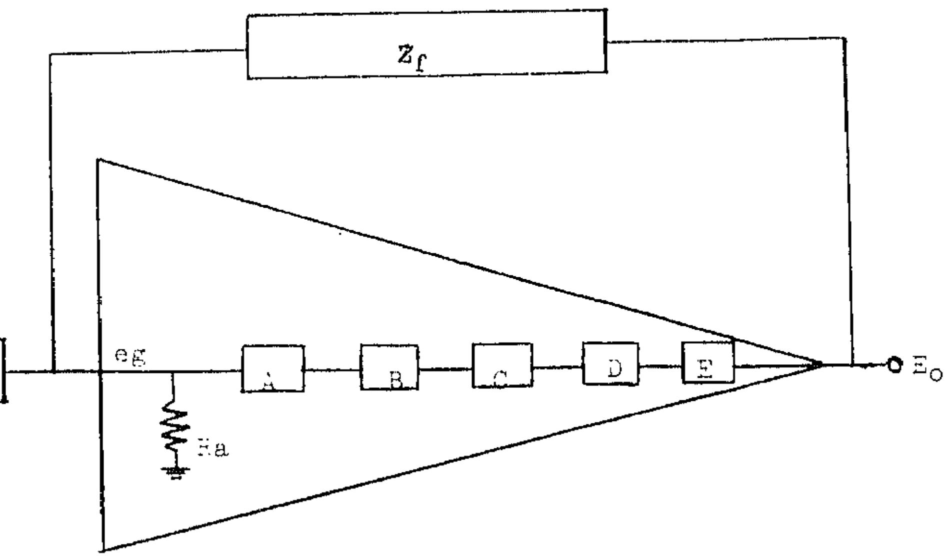


Figure 2

f. Blocks B through D are the d-c amplifiers
stage gain of only 100 then the over gain
circuit would be 1,000,000 1 x 100 = 100
100 = 1,000,000. Because there is an odd
stages, phase inversion always occurs.

g. The final stage again will be either a ca
or an emitter follower for further isolat

h. R_a is the base or grid resistor for the f
It develops e_g or the input potential for
section.

i. The effective input impedance is very low
found by the formula Z_{in} (of amplifier se
Some typical values are:

Z_f = 1 megohm

A = 50k

If they are put into the formula, then $\frac{1}{1+}$
approximately. The effective input imped
low.

j. The amplifier section's output impedance
Z_o of the amplifier section may be found
formula

$$Z_o = \frac{r_p}{1+AB} \text{ where}$$

r_p = plate resistance of the final am

B = ratio of input impedance to the s
and feedback impedance

$$B = \frac{Z_{in}}{Z_f+Z_{in}}$$

with some typical values r_p = 50kΩ

mpedances, and the type of impedance, specific
unctions such as algebraic summation, multiplication
r division by a constant, differentiation, integratio
nd other special function circuits.

ne input impedance, Z_{in}, is usually in the 500 k to 1
egohm range. It couples the input voltage from the
receding stage. It is also used as a current summing
etwork to reduce E_{in} to e_g the input voltage to the
mplifier section.

ne feedback impedance Z_f is also in the 500 k to 10
egohm range. It develops the output voltage E_o and
ouples the feedback current and voltage form output
nput.

operation

unction of the circuit in figure 3 is to reverse the
of the voltage, and give a gain of -1.

tion

ne input voltage E_{in} causes a current I_{in} to flow
nrough Z_{in}.

$$I_{in} = \frac{E_{in}}{Z_{in}}$$

f E_{in} is a positive voltage, then R_a will develop a
mall positive voltage (e_g) at the input to the ampli-
ier section. The amplifier section will amplify e_g
nd invert it (odd number of stages) causing a negati
o.

he resulting difference of potential between the inpu
erminal and output terminal will cause a current (I_{fb}
o flow through Z_f.

$$I_{fb} = \frac{-E_o}{Z_f}$$

f. Blocks B through D are the d-c amplifiers. stage gain of only 100 then the over gain circuit would be 1,000,000 1 x 100 = 100 x 100 = 1,000,000. Because there is an odd stages, phase inversion always occurs.

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B = ratio of input impedance to the su and feedback impedance

$$B = \frac{Z_{in}}{Z_f+Z_{in}}$$

with some typical values $r_p = 50k\Omega$

capacitive elements. According to the ratio of impedances, and the type of impedance, specific functions such as algebraic summation, multiplicati or division by a constant, differentiation, integra and other special function circuits.

The input impedance, Z_{in}, is usually in the 500 k t megohm range. It couples the input voltage from th preceding stage. It is also used as a current summ network to reduce E_{in} to e_g the input voltage to th amplifier section.

The feedback impedance Z_f is also in the 500 k to 1 megohm range. It develops the output voltage E_o ar couples the feedback current and voltage form outpu input.

of operation

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eration

The input voltage E_{in} causes a current I_{in} to flow through Z_{in}.

$$I_{in} = \frac{E_{in}}{Z_{in}}$$

If E_{in} is a positive voltage, then R_a will develop small positive voltage (e_g) at the input to the amp fier section. The amplifier section will amplify e and invert it (odd number of stages) causing a nega E_o.

The resulting difference of potential between the terminal and output terminal will cause a current to flow through Z_f.

$$I_{fb} = \frac{-E_o}{Z_f}$$

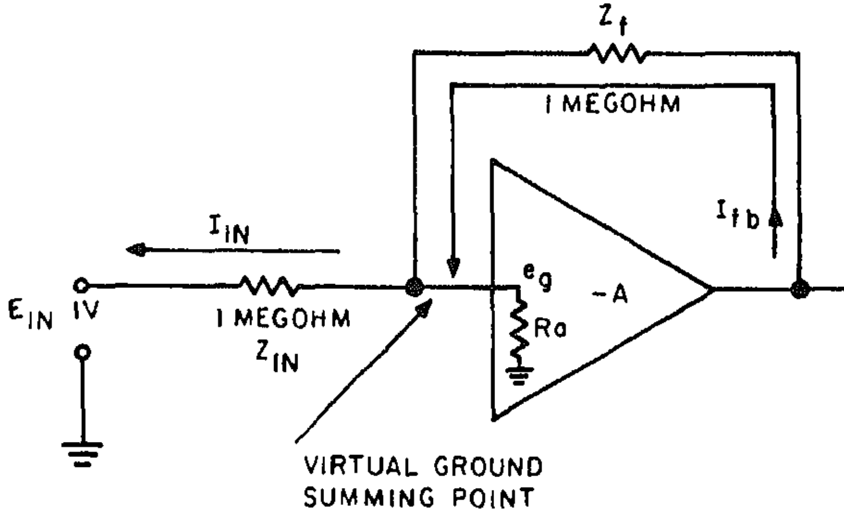


Figure 3

BASIC OPERATIONAL AMPLIFIER OPERATION

$$\text{Gain} = \frac{Z_f}{Z_{in}}$$

$$E_o = \frac{Z_f}{\quad} E_{in}$$

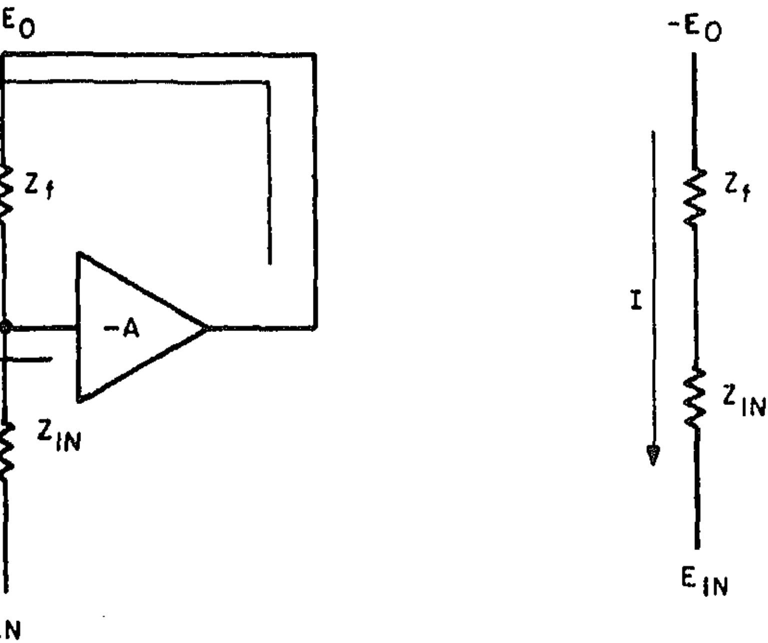


Figure 4

d I_{fb} appear in series and in series circuits
rrents are equal.

$I_{in} = I_{fb}$, then by algebraic substitution:

$$n = \frac{E_{in}}{Z_{in}} \; ; \; I_{fb} = \frac{-E_o}{Z_f}$$

$$\frac{n}{n} = \frac{-E_o}{Z_f}$$

g for E_o; multiply by $(-Z_f)$.

$$\frac{E_{in}}{Z_{in}}) = \frac{+E_o}{Z_f} (+Z_f)$$

$$E_o = \frac{-Z_f}{Z_{in}} E_{in}$$

E_{in}

transposing the formula. The gain of t

amplifier is determined by the ratio of

its circuit configuration and its funct

circuit.

j. In figure 3, then, with an input voltag
$Z_{in} = 1M$; $Z_f = 1M$. $E_o = \frac{-1M}{1M} 1V = -1V =$
Sign inversion and a gain of negative c

k. The feedback current (I_{fb}) is determine
Z_{in} and E_{in} and I_{fb} will equal I_{in} at a

l. With 1V in and Z_f and Z_{in} both 1 megohm

$$I_{in} = \frac{E_{in}}{Z_{in}}$$

$$I_{in} = \frac{1V}{1M}$$

$$I_{in} = 1\mu A$$

I_{fb} is equal to $\frac{Z_o}{Z_f}$

$$I_{fb} = \frac{-1V}{1M}$$

$$I_{fb} = 1\mu A$$

$$I_{fb} = I_{in}$$

m. If Z_{fb} is increased to 2 megohms with
remaining unchanged, then $E_o = -2V$.

$$I_{fb} = \frac{E_o}{Z_f}$$

$$= \frac{-2V}{2M}$$

1 = multiplication

y be performed if the $Z_f:Z_{in}$ ratio is less

1 = division

eg is very small and may be determined from

$_{in}$ A

eg is equal to $\frac{E_o}{A}$ where A is the open loop amplifier section.

2

as E_{in} and Z_f of 2M and Z_{in} of 1M, then

$\frac{V}{k}$ - open loop gain.

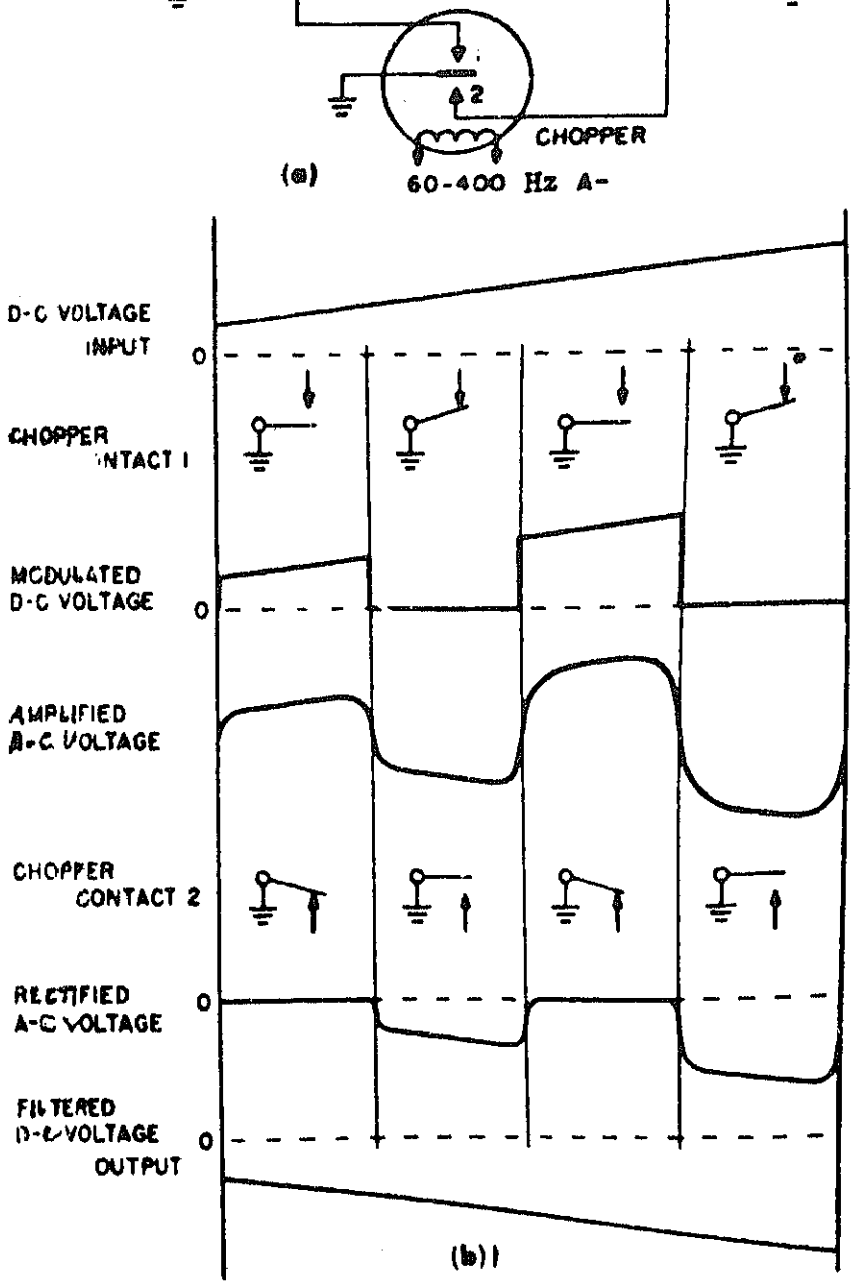
μV

at this point is called virtual ground. ve impedance is very small. Current flows point and away from it acting as a ground.

onal amplifier constantly seeks to obtain l ground. So, when E_{in} increases or E_o must correspondingly change, by amplifier cause a current to flow through Z_f that just e current flow through Z_{in}.

amplifiers are self regulating. If E_o ue to amplifier gain, component variation,

k increases.



The chopper amplifier.

of voltage would be fed back through Z_f and, after processing by the chopper amplifier, would end up as a negative balance signal at the B terminal, reducing the output offset voltage to zero. A similar action occurs for negative drift voltages except that the polarities of the involved signals would be reversed.

To illustrate the properties of high-quality computer amplifiers using chopper stabilization, some representative specifications are tabulated below:

Gain of the d-c amplifier channel, 30,000 to 150,000

Gain of the automatic balancing channel, 2000 to 3000

Total d-c gain, 25 x 10^6.

Grid current, less than 10^{-4} μA.

Average drift over an 8-hour period, 20 to 200μV.

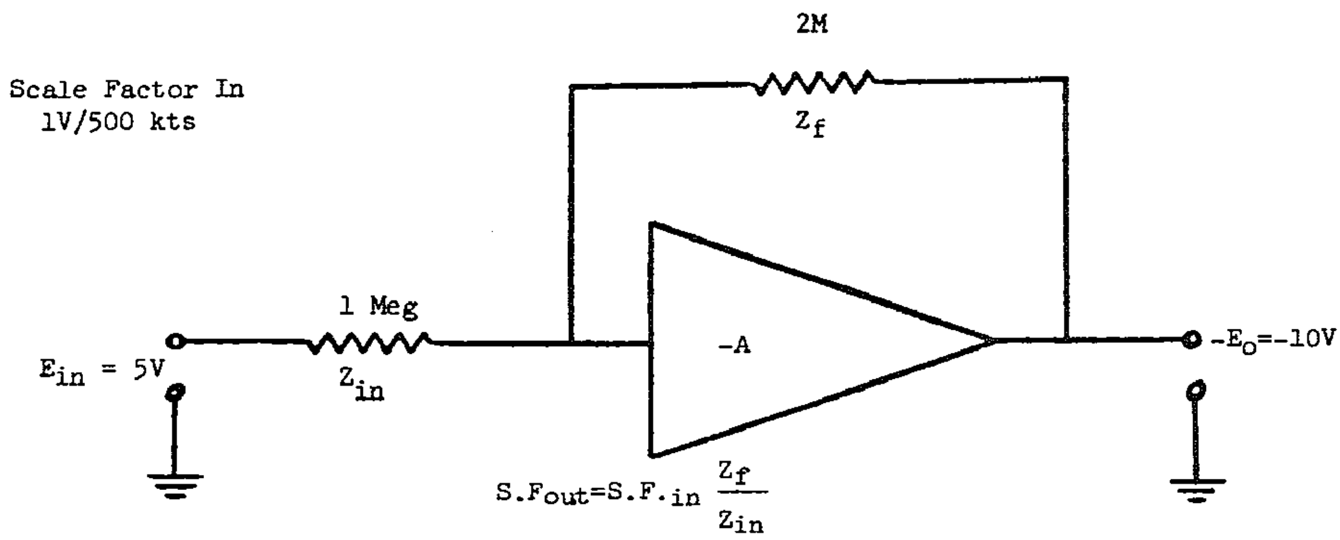
Linear output range, at least ± 100 volts into rated load; decreases above 100 Hz, depending on tube types

Factors

The input scale factor will be changed by the gain of an amplifier. In an isolation amplifier with a gain of -1, a Z_f/Z_{in} ratio of one, there will be no scale change. There is no change in analog units; therefore, no change in scale factor. If the gain of the circuit is more or less than 1, the scale factor must be changed.

The identity process is used to change scale factors.

If the output voltage is different from the input voltage, then the ratio of analog units to equation units must also change. Refer to figure 7. In figure 7, the Z_f to Z_{in} ratio is -2. With 5V in, E_{out} is -10V. The input voltage represents 2500 knots; therefore, by the law of identity the output voltage must also represent 2500 knots. This means the scale factor must be changed. The output voltge would represent 5000 knots, unless the scale factor is changed.



BASIC SCALE CHANGING OPERATIONAL AMPLIFIERS

Figure 7

$$SF_o = SF_{in} \frac{Z_f}{Z_{in}}$$

$$SF_o = (1V/500 \text{ kts})(\frac{2}{1})$$

$$SF_o = \frac{2}{500}$$

$$SF_o = \frac{1V}{250} \text{ kt}$$

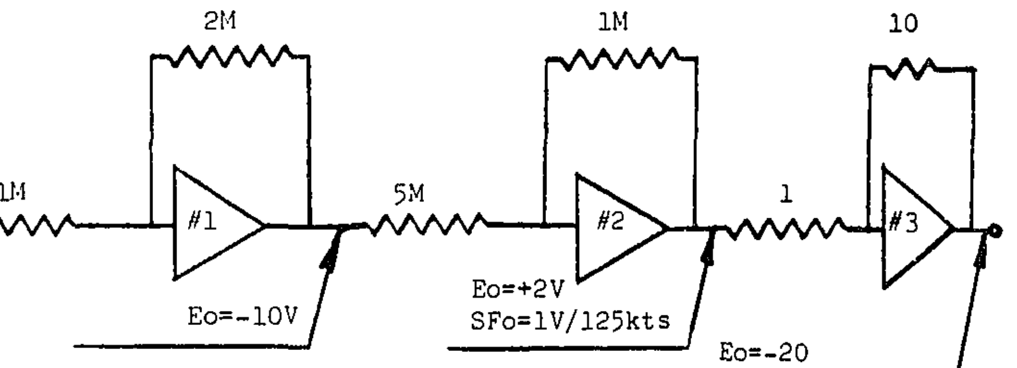
ne new scale factor 1V/250 kts, the output voltage
till represents 2500 knots.

Equation units = S.F. x analog units

= (1V/250 kts)(-10V)

2500 kts out = 2500 kts in

alog devices, input variables must be scaled to
sent the same information (equation units) in
rent modules of the device. This may be accomplished
e circuits shown in figure 8. Note that the input
mation to amplifier #1, 250 knots of airspeed from the
eed circuits is represented by 5V at a scale factor



in					out
Amp #1	5V	1V/50 kts	250 kts	-10V	1V/25 kts
Amp #2	-10V	1V/25 kts	250 kts	+ 2V	1V/125 kts
Amp #3	+2V	1V/125 kts	250 kts	-20V	1V/12.5 kt

Figure 9

H. Basic Operational Amplifier Circuits

1. The circuits covered below are some basic ope amplifier circuits covered in outline form. only basic circuits. There are many more.

2. Summing Amplifiers are used as an electronic circuit. E_o represents the algebraic sum of voltages.

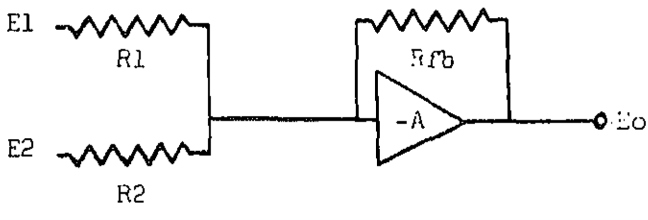


Figure 10

Summing Amplifier

Definition - An operational amplifier with mo input.

3. Operational amplifier switch operates as a sw operating point determined by the bias potent

   a. With no voltage present on R1 and with E2 voltage, the output voltage will be posit diode CR_1 to conduct.

   b. Resistance of CR_1 when conducting is very

   c. Output voltage would be near zero.

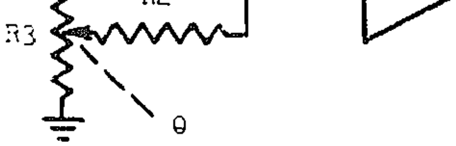


Figure 11

Operational Amplifier Switch

l that resistance of conducting diode is about
hms.

$$E_o = \frac{-Z_f}{Z_{in}} E_{in}$$

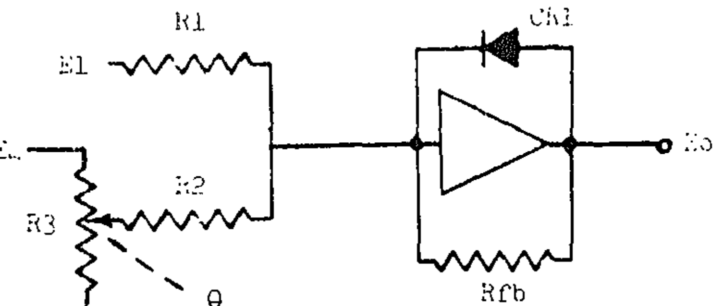
$$E_o = \frac{-100}{1M} E_{in}$$

E_o is very small

input potential on R1 becomes sufficiently
ive to drive input to a positive voltage E_o will
e negative and diode CR_1 becomes reversed biased.

eedback impedance increases and gain switches from
o high.

specific gain is desired, a resistor is placed in
lel with the diode.



4. Logarithmic amplifier

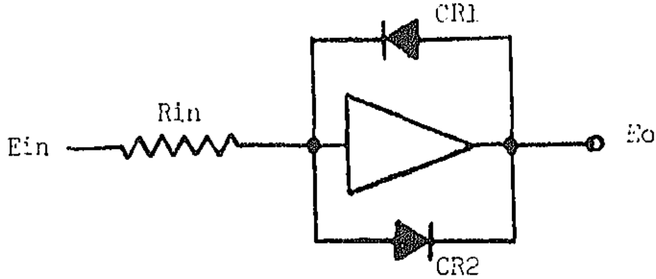


Figure 13

Logarithmic Amplifier

a. Diodes CR_1 and CR_2 are special function diod
variable conduction level.

b. Two diodes are used so that there may be bot
and negative inputs.

c. As input voltage increases in amplitude, one
the other, depending on the polarity of the
conducts.

(1) As diode conducts harder, current flow

(2) It seems as if Z_f had decreased.

d. This results in a logarithmic gain for this

(1) High gain for small signals because of
duction, therefore high resistance of di

(2) Low gain for larger signals.

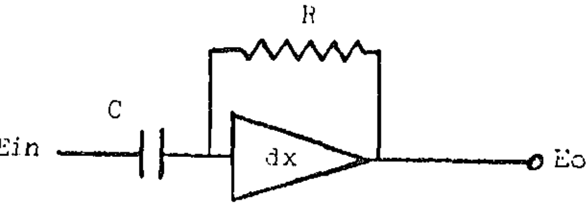
Figure 14

Integrating Amplifier

ates input voltage with respect to time by
lating charge on capacitor.

ample, if an input voltage waveform represented
ration, the output voltage would be the integral
eleration, i.e. velocity.

ating Amplifier



$$\frac{ds}{dt} = V \text{ out}$$

Figure 15

Differentiating Amplifier

entiates input voltage.

voltage represents derivative of input.

ample, if the input voltage represented displace-
then the output would represent ds/dt or V.

c Circuits, NAVSEA 0967-LP-000-0120, pages 5-279 to

r and Integrated Electronics, Kiver, M. S.,
li, Fourth Edition, 1972, pages 306 to 310.

d Circuits and Semiconductor Devices, Deboo and
McGraw Hill, Second Edition, 1977, Chapter 4.

cs Communication, Schrader, R. L., McGraw Hill,
ition, 1980, pages 216 and 317.

TLINE:

t-Coupled Amplifiers

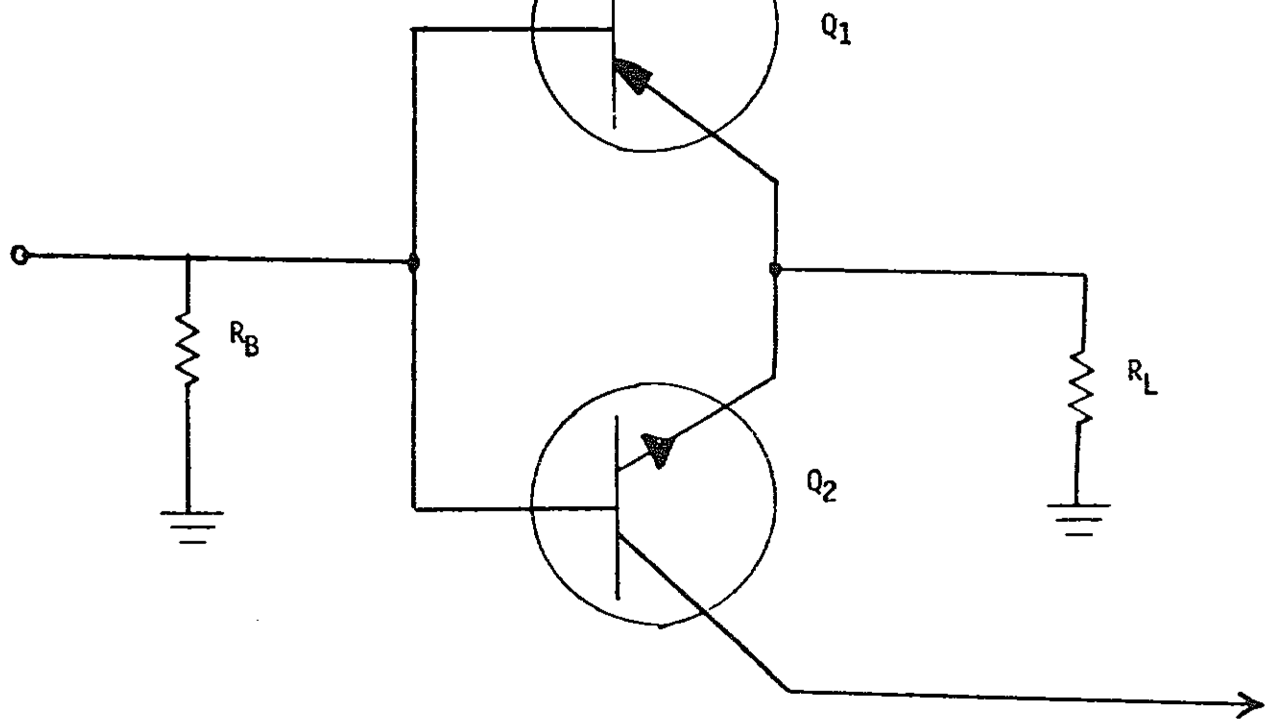


Figure 1 - Complementary Symmetry

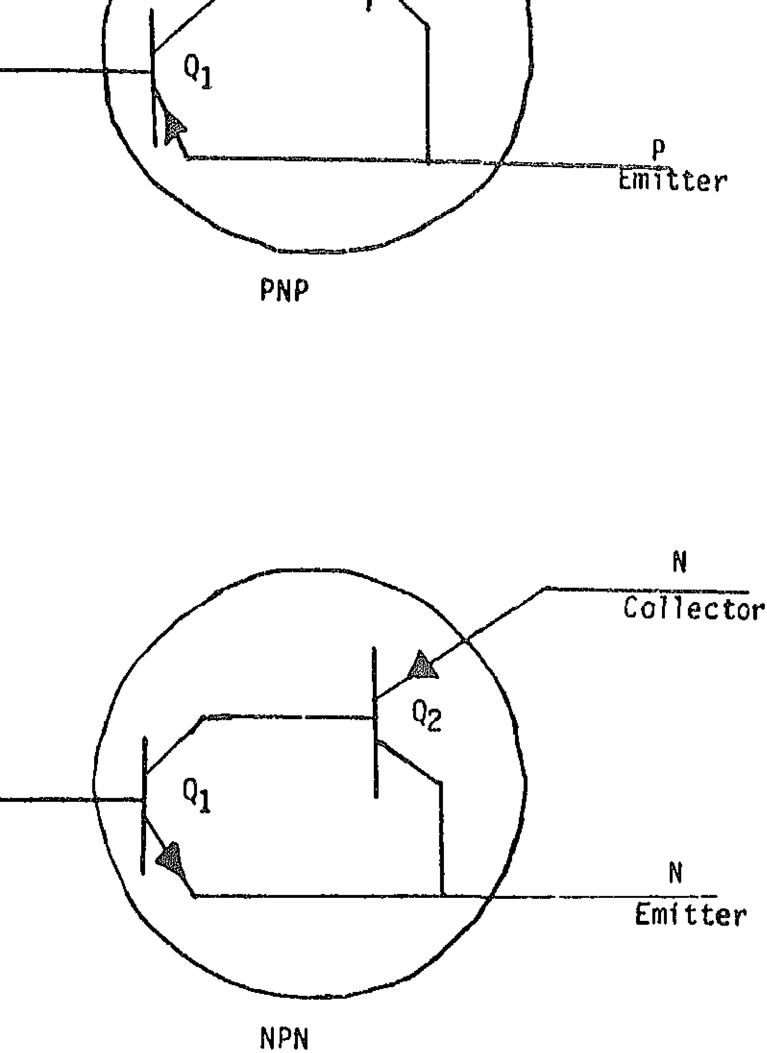
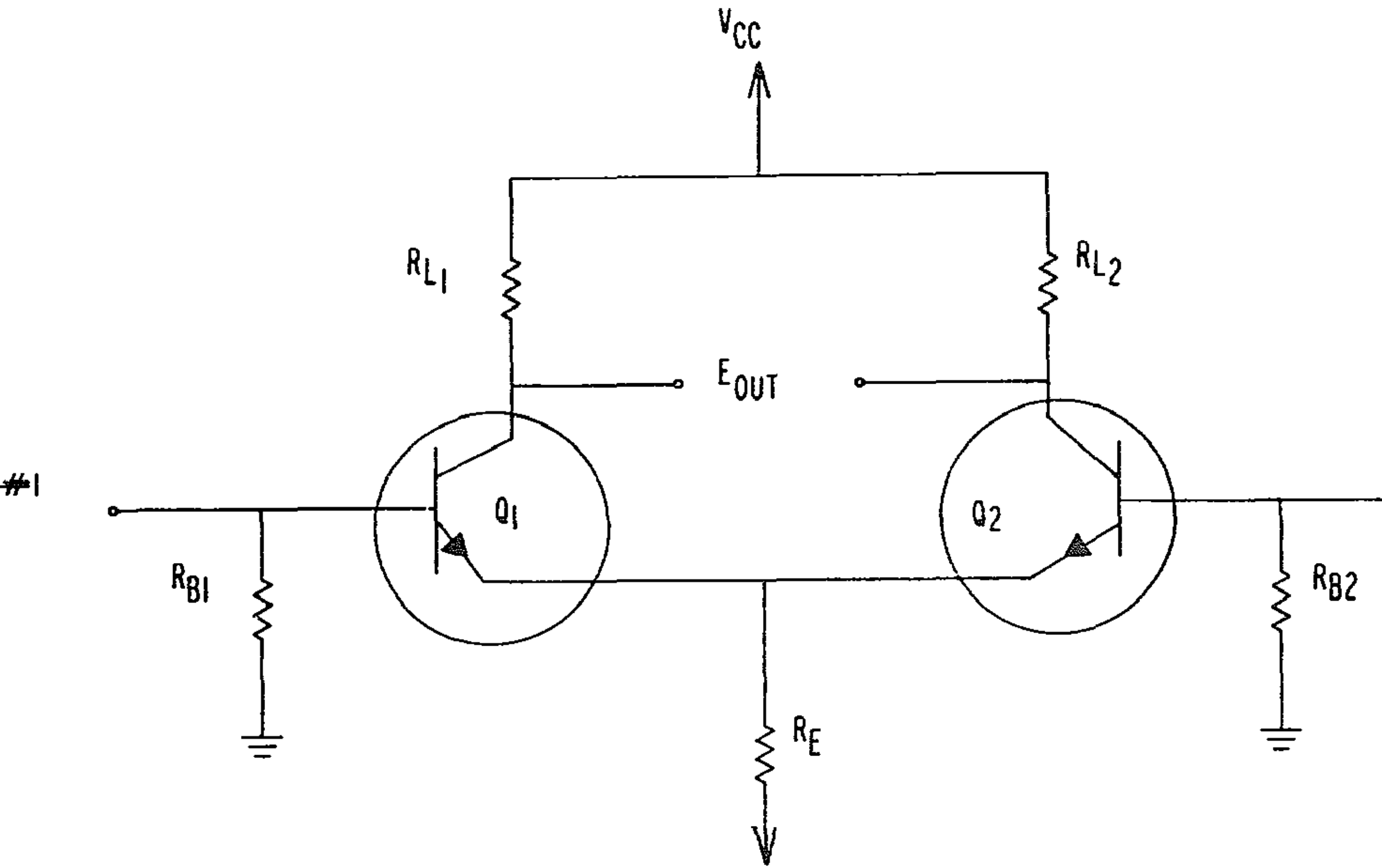


Figure 2.-Complementary Darlingtons.



Output Differential Amplifier

Jses

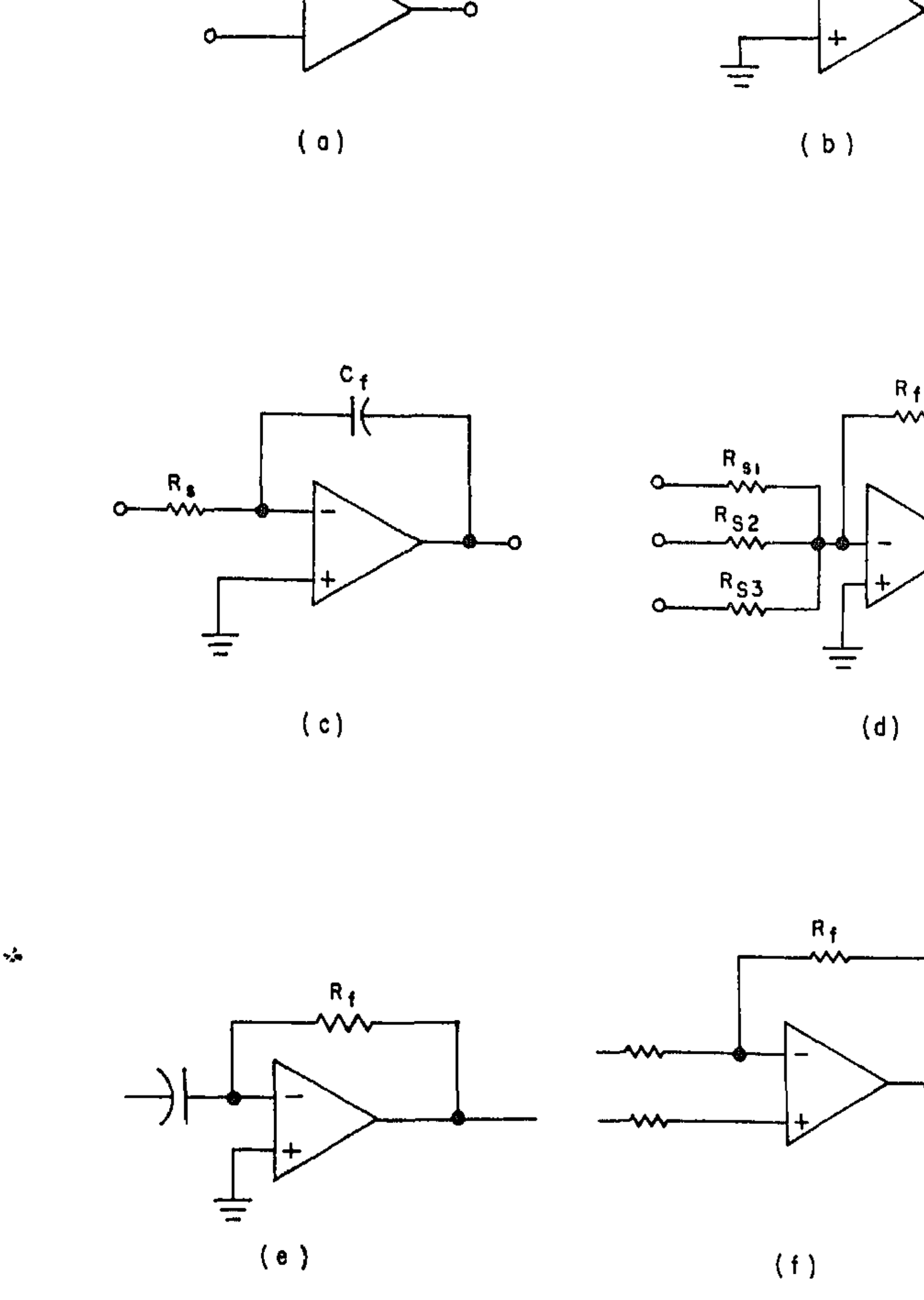
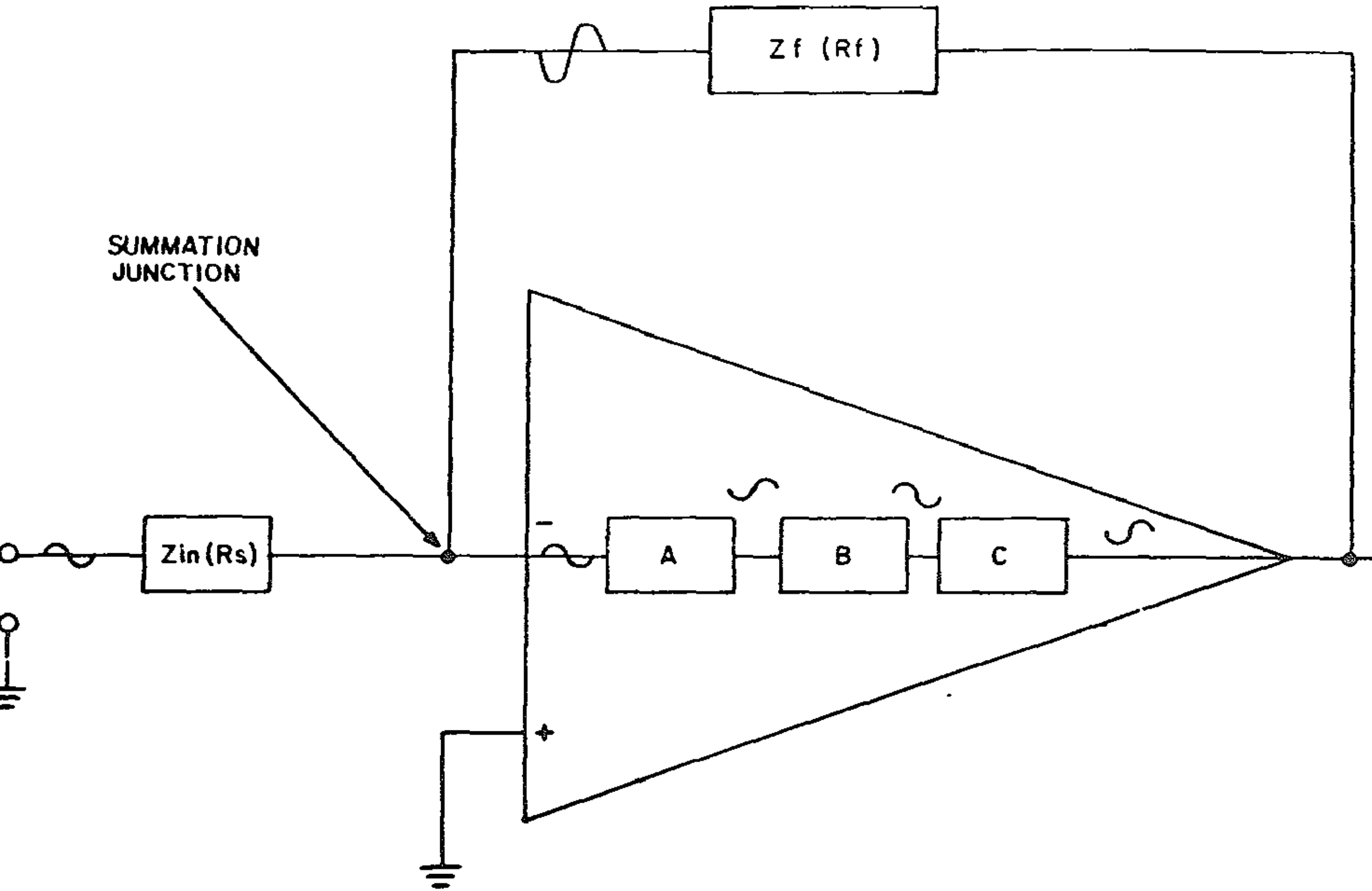


Figure 4.-Operational Amplifier

atic symbol

functional analysis


Zf (Rf)
SUMMATION
JUNCTION
Zin (Rs)
−
+
A
B
C

al amplifier

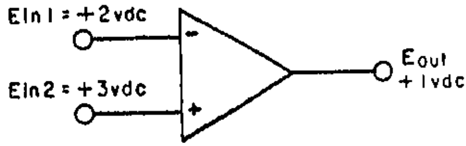
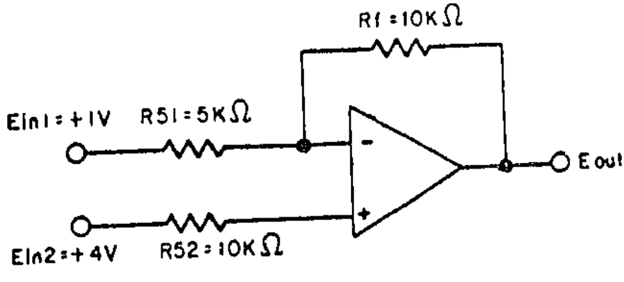


Fig. 3 DIFFERENTIAL AMPLIFIER (basic)

Figure 6

nce ratio

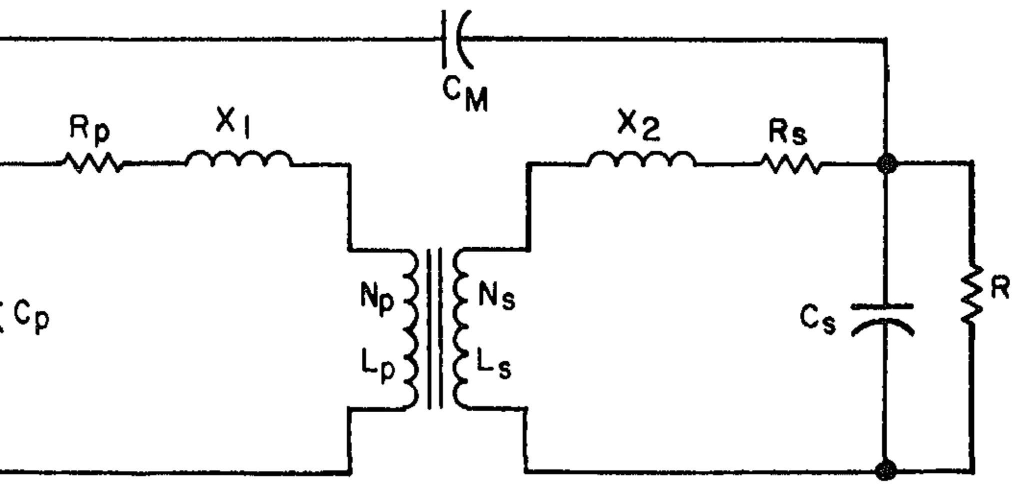


N

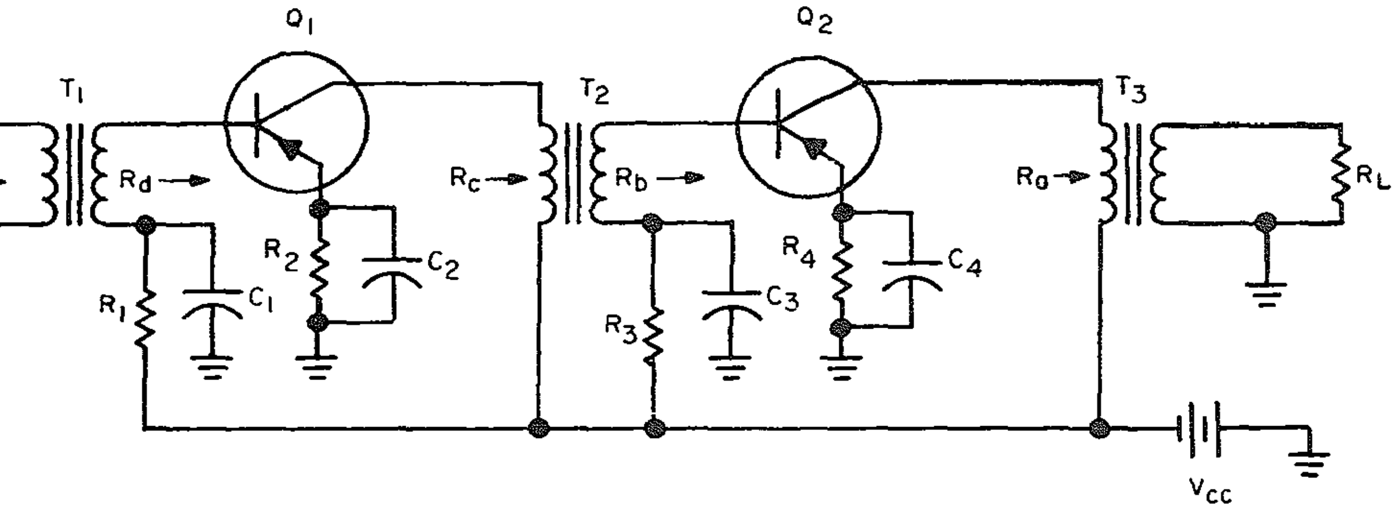
onic systems, ranging from voltage regulators to comp
tion systems, require the amplification of d-c and a-
Many times one stage of amplification is not sufficie
amplitude of such signals to the required values;
the different types of coupling are necessary to ensu
m transference of energy is required. This lesson on
coupling is essential for the technician.

S. Kiver, Transistor and Integrated Electronics.
Hill Book Company, Fourth Edition, 1972.

L. Shrader, Electronic Communication, McGraw-Hill Boo
, Fourth Edition, 1980.



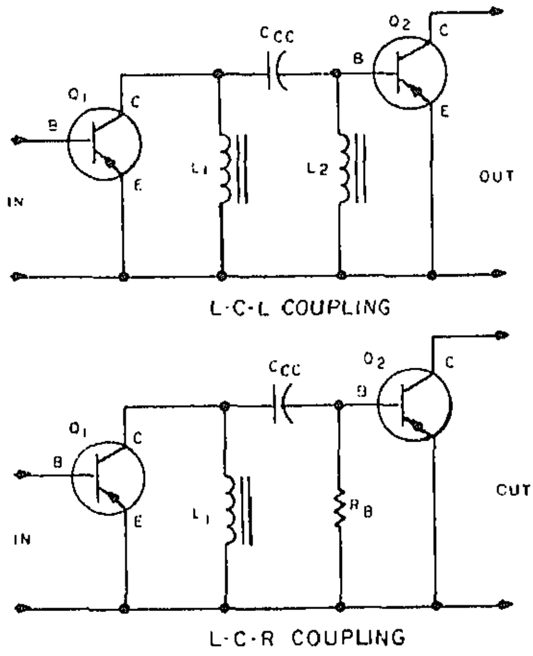
TRANSFORMER EQUIVALENT CIRCUIT



TRANSFORMER-COUPLED TRANSISTOR AMPLIFIER

Figure 2

of an inductor provide more output than the load resistor. While the overall frequency response of impedance coupling is not as good as that of resistance coupling, it is much better than that of transformer coupling, because there are no leakage reactance effects to deteriorate the high-frequency response. The high-frequency response of the impedance coupler is limited mainly by the collector output capacitance, and the low-frequency response is limited by the shunt reactance of the inductor, L1. The efficiency of the impedance coupler is approximately the same as that of the transformer-coupled circuit (50% for the ideal case). See figure 3.



Impedance-Coupling Circuits

Figure 3

2. Transformer coupling--Transformer coupling is used extensively in cascaded transistor stages and power output stages. It provides good frequency response and proper matching of input and output impedance

3. Coupling between stages is achieved throu
inductive coupling of primary and seconda
Since these windings are separated physic
input and output circuits are isolated fo
yet coupled for a-c signal transfer. The
winding presents a low d-c resistance, mi
colector current losses and allowing a lo
collector voltage for the same gain as ot
methods, and it presents an a-c load impe
following stage. The secondary winding a
the base d-c return path and provides bet
stability because of the low d-c (winding
Since the transistor input and output imp
matched by using the proper turns ratio,
able gain can be obtained from the transi

4. As in the impedance coupler, the shunt re
transformer windings causes the low-frequ
to drop off, while high-frequency respons
by the leakage reactance between the prim
secondary windings, in addition to the em
lector capacitance. Because of the low d
in the primary winding, no excess power i
and the power efficiency approaches the m
theoretical value of 50%.

B. Transistor impedance-coupled audio amplifier

1. Application--The impedance-coupled transi
amplifier is used where higher gain than
stage is desired with better response tha
vided by transformer coupling.

2. Characteristics

a. Uses common-emitter circuit for highe

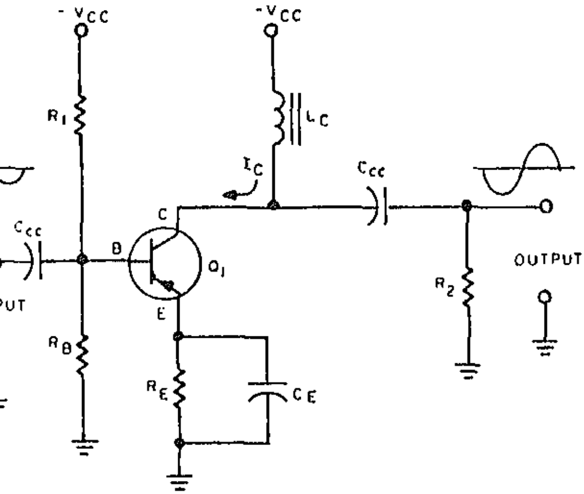
b. Operates class A for linear operation
distortion.

c. Usually amplifies small signals, but
signed to handle large signals in cas

d. Is fixed-biased from the collector s

impedance-coupled transistor amplifier is
...ar in a general sense to the impedance-coupled
...ron-tube amplifier.

...e 4 shows a conventional PNP, triode, common-
...ter impedance-coupled transistor audio ampli-
circuit.



...edance-Coupled Audio Amplifier

Figure 4

...input is shown capacitively coupled, and volt-
...divider R_1, R_B provides fixed bias form the
...ector supply. Emitter swamping is provided by
...or temperature stabilization; R_E is bypassed by
Collector impedance L_C is the load across
... the output voltage is developed; this voltage
...plied through coupling capacitor C_{CC} to the
...ut circuit. Resistor R_2 is the base-to-ground
...stor in the next stage when cascaded amplifiers
...used, or is the output load resistor (such as a
...set) in a single-ended stage. (In some appli-
...ons, R_2 may be replaced by an iron-cored
...ctor similar to L_C.

developed across R_B; this bias is su
cause the quiescent value of I_C to f
though the collector is reverse-bias

d. When the input signal goes positive, sinewave iput, the forward base bias instantaneously by the amplitude of signal, and collector current I_C is reduction in collector current cause across collector impedance L_C to dec toward the supply voltage, which is a negative-swinging output signal is When the input signal becomes negati the forward base bias and causes I_C The increase in collector current th duces a large voltage drop across th reduces the negative collector volta duces a positive swing. Therefore, output follows the input signal exce reversed in polarity; when the input positive, the output signal is negat versa. The collector output is deve the impedance of L_C between the coll ground, and is applied through coupl C_{cc} to the base of the next stage, o load.

e. In cascaded impedance-coupled stages resistor and base-to-emitter interna the next stage transistor offer a sh between coupling capacitor C_{cc} and g fore, the reactance of C_{cc} and the t resistance (or impedance) from resis first stage. If the reactance of th capacitor is large, the output volta attenuated, and ony a small output a base and ground of the second stage. reactance of C_{cc} varies inversely wi the lower audio frequencies are atte than the higher frequencies. For go frequency response, the coupling cap sufficiently large in value that its very small as compared with the base resistance or impedance. This is si vacuum-tube practice, where relative

capacitor should always be less than one-tenth the effective base input impedance.

In those circuits where an impedance replaces R_2, the coupling capacitor and inductor can be made to series-resonate at a low frequency to provide base boost. At the higher audio frequencies (about 15,000 Hz), the collector-to-emitter shunting capacitance of the second stage, together with the large distributed capacitance from turn to turn of the collector-inductance, tend to bypass the high frequencies to ground, causing a drop in the response.

The frequency-attenuating action produced by the transistor occurs because the width of the internal transistor PN junctions is voltage-sensitive. With higher voltage, the transition region is narrow, corresponding to the closely spaced plates of a capacitor with the associated high capacitance. The reverse bias on the collector also reduces the width of this transition region, so that transistors are generally characterized by a high interelectrode capacitance. For example, an audio transistor may have a collector-to-base capacitance on the order of 50pF, as compared with a vacuum-tube plate-to-grid capacitance of one or more pF. The collector-to-emitter capacitance is usually 5 to 10 times the value of the collector-to-base capacitance (in the common-emitter circuit), as compared with 8pF or less for vacuum-tube plate-to-cathode capacitance. Thus, it can be seen how the high-frequency response is affected considerably by internal transistor parameters. Of course, any shunt wiring capacitance and that of the collector inductance will also add to the shunting effects of the transistor. Both low-and high-frequency compensating circuits may be used to increase the frequency response of the circuit.

Over the region of 100 to 15,000 Hz, the impedance-coupled amplifier has a relatively flat response, and with proper matching will afford high power and voltage gains. Hence, this form of coupling is

i. Transistor audio amplifiers are also
by a high inherent noise which is gr
lower audio frequencies. Operating
of emitter current and low collector
together with low values of input re
to minimize the noise. By using an
place of the base-to-ground resistor
the schematic), a very low input res
lower noise figure over that of the
amplifier, is obtained. In the comm
degenerative effects produced by an
emitter resistor tend to increase th
sistance. Thus, it is conventional
large emitter bypass capacitors to a
possibility of degeneration. As wit
tubes, external feedback circuits pr
response, although emitter degenerat
times be used. Since fixed bias fro
supply may be easily obtained by a s
divider, it is used in both large-an
applications. Self-bias is generall
use to very small-signal amplifiers;
distortion and improper operation wi
in gain, or blocking, may occur on l
The emitter resistor functions mainl
resistor for temperature stabilizati
vents large changes in amplification
temperature variations.

j. In considering the operation of the
impedance-coupled amplifier as compa
electron-tube impedance-coupled ampl
should be clear from the above discu
circuit is an almost exact counterpa
the other. The difference is that t
stages operate with low input and ou
ances, at low voltages, and at very
amplification, whereas electron-tube
with relatively high input and outpu
at high voltages, and at high levels
tion. Thus, the transistor is basic
amplifier, while the electron tube i
amplifier. Consequently, the transi
closer matching (rather than mismatc
impedances to maximize performance

Characteristics

a. Uses common-emitter circuit for higher gain.

b. Operates class A for linear operation and minimize distortion.

c. Usually amplifies small signals, but can be designed to handle large signals in cascaded stages.

d. Is fixed-biased from the collector supply, but may use self-bias in some applications.

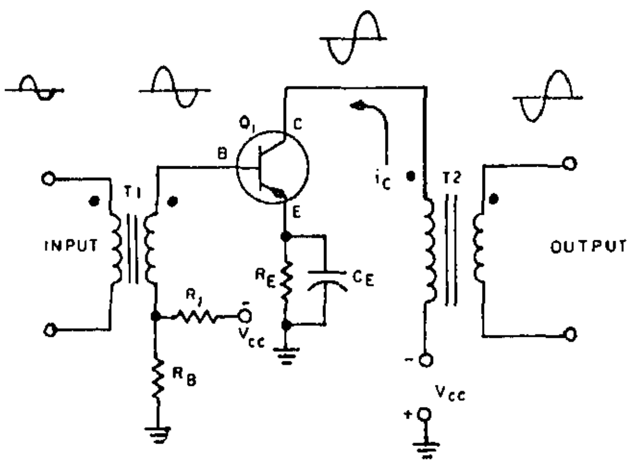
e. Emitter swamping is normally used for thermal stabilization.

f. Gain is fairly uniform over a range of approximately 100 to 10,000 Hz or more.

g. Both voltage and power gains are high.

Circuit analysis

a. The transformer-coupled transistor amplifier is similar in general to the transformer-coupled electron-tube amplifier. See figure 5.



lization; R_E is bypassed by C_E. The ou
transformer-coupled through T2.

c. The use of T1 to apply the input signal
circuit provides an almost ideal temper
sponse characteristic. The low transfo
resistance produces a low base input re
when used with emitter swamping resisto
variation in gain with temperature is r
very small value over a large range of
(greater than for any other type of cou
cuit). Normally, transistor Q_1 rests i
quiescent condition, with class A bias
voltage divider R_1, R_B. The quiescent
current, I_C, is steady, producing only
constant voltage drop across the primar
of T2. Thus, practically the full valu
tor supply, V_{CC}, is available. With a
collector current, no voltage is induce
secondary of T2, and there is no outpu
input signal or noise). When a positiv
signal is introduced into the input ci
flow through the primary of T1 induces
the secondary, which is applied to the
Assuming that the transformer secondary
in-phase with the primary, a positive
voltage appears at the base. This pos
swing cancels the forward negative bias
duced flow of collector current occurs
instantaneous collector current decrea
primary voltage drop also decreases, an
collector voltage to rise toward the n
voltage. Meanwhile, the reducing colle
induces a voltage in the secondary win
secondary winding is connected in-phase
reducing collector current produces a
voltage swing in the secondary, and an
current produces a positive swing. The
current flowing through R_E is the stea
value, and any change in base bias with
is bypassed around the emitter resisto
capacitor C_E. Although the capacitor
the quiescent d-c current, it will pas
nating audio voltage produced by the c
signal. Thus, only d-c current change

the forward bias and hence reduces the collector current back to the original value so that it appears unchanged. If the emitter bypass capacitor were not used, the input signal voltage would produce a degenerative effect, since all collector and emitter current would be forced to flow through the emitter resistor.

Consider next the next negative swing of the input signal. In this instance, the forward bias on the base element is increased (the two negative voltage add), and a heavy collector current flow occurs. The increasing I_C through the primary of T2 induces a voltage into the secondary. Assuming the same in phase connection of the primary and secondary, the output voltage is positive. By changing the connections of the secondary winding of either T1 or T2, the signal can be changed so that it is of the same phase at both the input and the output; this i an advantage of transformer coupling.

Since the secondaries of T1 and T2 are not connecte to their primaries, the transformers offer a convenient method of separating input or output signal from bias or collector voltages. By using the proper turns ratio, the primary and secondary impedances may be matched. In the base circuit, th input resistance is matched, giving maximum gain; likewise, in the output circuit, the proper turns ratio reflects the secondary load impedance into th primary, which, when added to that of the transformer primary itself, provides a matched load for maximum output.

Normally, the transformer-coupled stage is operated in the middle of its transfer characteristic to produce linear amplification. It is also a small-signal amplifier when used in preamplifier stages. In following cascaded stages, it becomes a large-signal amplifier, operating with a larger bias over the linear range of its transfer characteristic. When necessary, bias resistor R_B is bypassed to ground with a large capacitor to prevent audio signal voltages from causing the bias to change wit the signal, particularly in high-gain and large-

stages, the flow of reverse (leakage) c
through the collector-to-base junction
important when it is a large percentage
operating collector current. Thus, the
chooses a transistor with as large a be
possible, and as small a leakage curren
obtained, in order to get the most gain
least leakage current. (The flow of re
does not occur in electron tubes.)

h. The frequency response of the transform
amplifier is lower than that of the res
or impedance-coupled transistor audio a
There is more shunting capacitance than
tance coupling because of the transform
tributed turn capacitance, and there is
inductance between the primary and seco
does not exist in the impedance-coupled
primary inductance is usually made from
load resistance, R_L, for good low-frequ
ponse. However, the lower the frequenc
the inductive reactance, so that the re
to drop at low frequencies. The high-f
response is primarily determined by the
of shunting capacitance with load resis
linkage inductance, while the low-frequ
is detrmined by the combination of load
and magnetizing inductance. In additio
shunting capacitance and inductance for
circuits which produce humps in the res
Practically speaking, the response is v
to that of the electron-tube transforme
audio stage, with somewhat less high-fr
response. Loss of low-frequency respon
pared with the electron-tube circuit be
apparent when miniaturized transformers
because of the difficulty of building t
with a sufficiently large iron core to
high inductance with the limited number
available in the space allocated.

iver, Transistor and Integrated Electronics. Book Company, Fourth Edition, 1972.

hrader, Electronic Communication, McGraw Hill y, Fourth Edition, 1980.

Instruction, Transformers, M135.

INE

ges/Disadvantages

rmer Theory

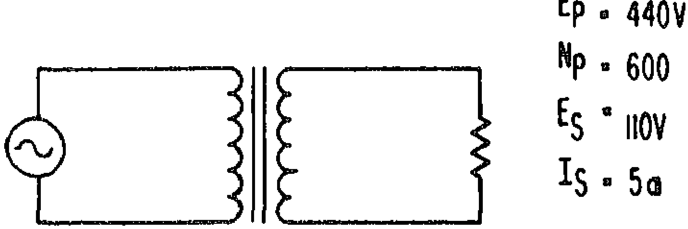


Figure 1

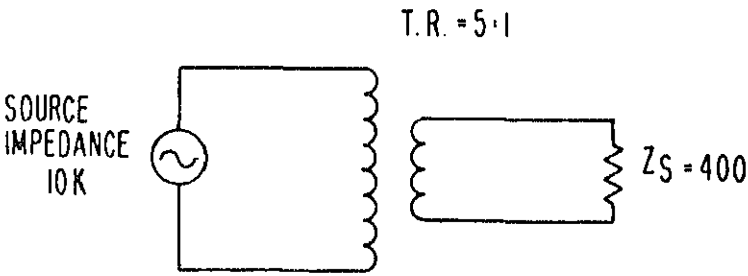


Figure 2

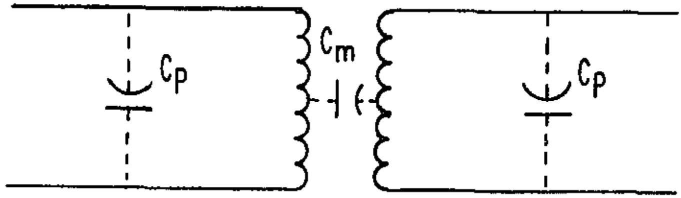


Figure 3.- Distributed Capacitances in Transfo

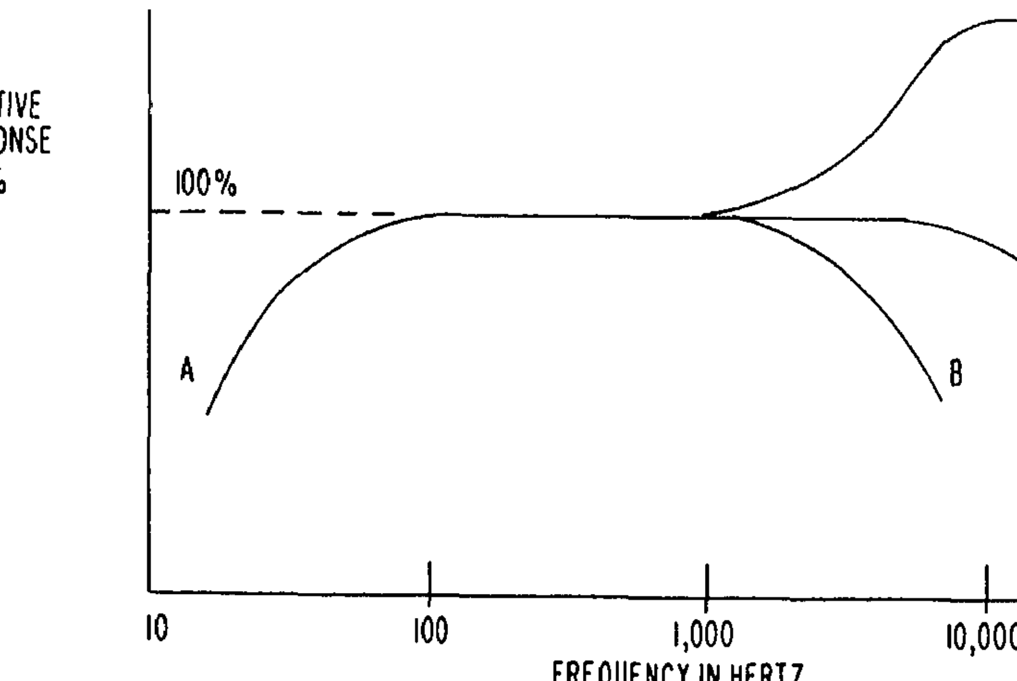


Figure 4.- Frequency R

ION

e the development of solid state devices, the ability
to amplify or control has been under constant invest
Manufacturers have been forming layers of semiconduct
, inserting PN junctions, shaping new geometries, and
oping levels in the search for new control or amplify
Some of the newly made special devices parallel tran
aracteristics; while other devices completely take ov
that a transistor cannot perform. At the present
-the-art", several devices will be explained in this
on.

S

ronic Circuits, NAVSHIPS 0967-000-0120.

n S. Kiver, Transistor and Integrated Electronics.
w-Hill Book Company, 1972, Fourth Edition.

ny S. Manera, Solid State Electronic Circuits: for
eering Technology, McGraw-Hill Book Company, Inc., 19

t P. Malvino, Ph.D., Electronic Principles, McGraw-Hi
Company, Inc., 1979, Second Edition.

ON

CONSTRUCTION AND OPERATION OF JFET

FET Construction

. The Junction Field-Effect Transistor (JFET) is a s
state device with a very high input impedance and
high output impedance--two favorable attributes al
found in vacuum tubes. Like a vacuum tube, the JF
a voltage-controlled device. (The conventional tr
sistor is a current-controlled device.) In its op
tion and construction, the JFET is completely diff
from a vacuum tube, yet many circuits of both are
similar. The JFET is a semiconductor device with
filament, so no excess heat must be dissipated. I
be operated at high voltages comparable to those o
small vacuum tubes, or with the low voltages norma

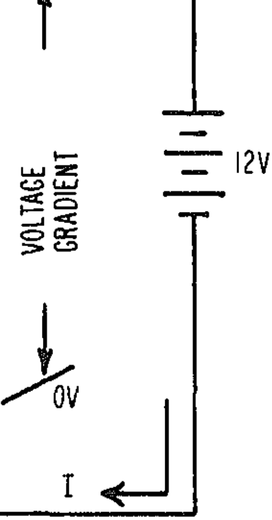
lators. They also are used in small-sign
video amplifiers. A few high-power junct
effect transistors are available with hig
capabilities. As the demand rises and pr
techniques improve, higher power JFETs wi
marketed.

4. Like most solid-state devices, field effe
are temperature sensitive, but not as muc
tional (bipolar) transistors. Input and
tances of the FET are moderate. Both tem
capacitance problems are reduced when app
external circuit designs are used. JFETs
destroyed quickly if maximum ratings are
in the production of many solid-state dev
are wide variations in units of the same
formance specifications are not too stric
limitation also can be compensated for by
ternal circuit design.

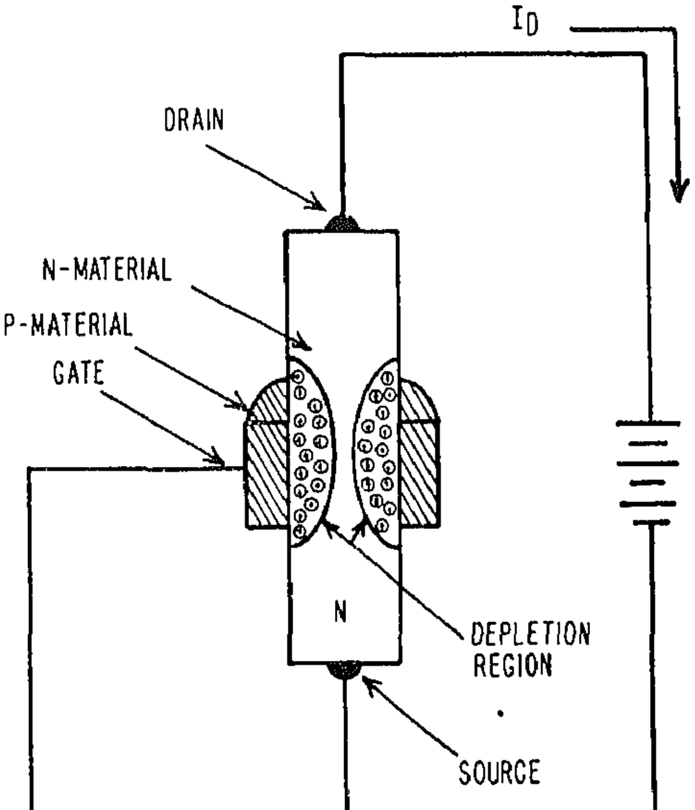
5. The simplified JFET structure shown in fi
helpful in obtaining a fundamental unders
JFET operation. First imagine simple ba
material with direct (ohmic) contacts at
excess electrons are available in the mat
voltage source connected across the leads
movement of electrons. The magnitude of
flow depends on the applied voltage, the
doping, and the dimensions of the semicon
Of course, the larger the cross-sectional
bar, the lower the resistivity. Likewise
the doping of the N-type material, the lo
resistivity.

6. It is not feasible to vary the physical d
the bar or its doping level; however, it
influence the *movement* of charges by chan
resistivity of the bar. This can be done
by varying the depletion region.

7. The connection of a voltage source betwee
(figure 1A) sets up a voltage gradient al
semiconductor material. The voltage at a
becomes more positive as one proceeds alo



VOLTAGE GRADIENT
12V
0V
I



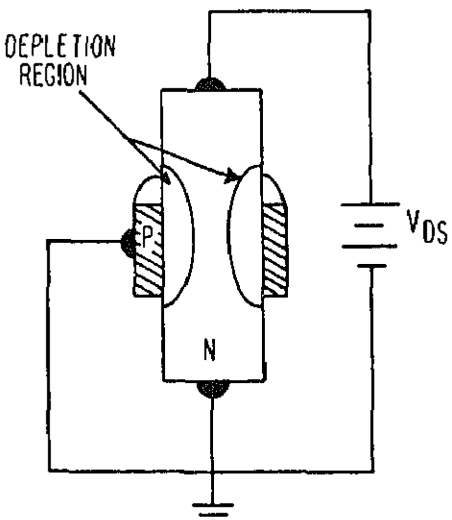
I_D
DRAIN
N-MATERIAL
P-MATERIAL
GATE
N
DEPLETION REGION
SOURCE

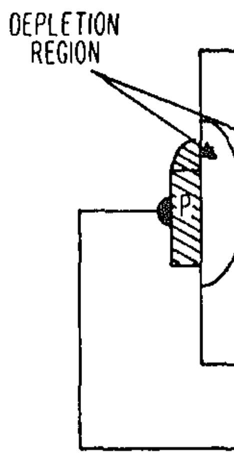
reverse bias on the junction is obtained
positive gradient that extends from the
the bar to the positive end.

9. In previous lessons, the influences of a
on the depletion regions associated with
were detailed. It is this activity that
control the movement of charges through
JFET terminology the bar is called a cha
fore, figure 1(B) is an N-channel JFET).
that controls the motion of charges alon
is called the gate. The common end of t
its associated lead is known as the sour
opposite end of the channel and its asso
called the drain. The gate can be compa
control grid of a vacuum-tube--the sourc
be compared to the cathode and plate res

B. Influence of the Reverse-Biased Junction

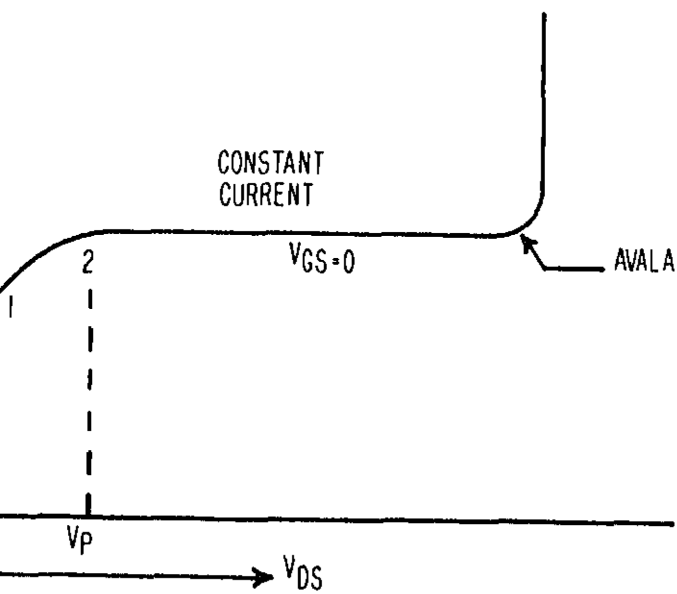
1. A reverse-biased junction causes the dev
depletion region in the channel, as show
Adequate doping keeps the resistivity of
material lower than that of the channel





ce of the depletion region in the channel
increase in the resistivity of the bar. If
source voltage (V_{DS}) is increased, the
region extends farther into the channel,
its resistance. In figure 2(B) the
region would seem to extend through the
such a manner that channel current would be
"pinched off."

however, counteracting influences that pre-
omplete pinch-off of the current. Increasing
to increase the current, while a larger de-
gion tends to reduce it; thus, current is not
The combined influence of the depletion
the voltage drop establishes a condition in
current rises to a maximum and then holds
further increase in channel current with an
n V_{DS}). This is indicated by the curve in

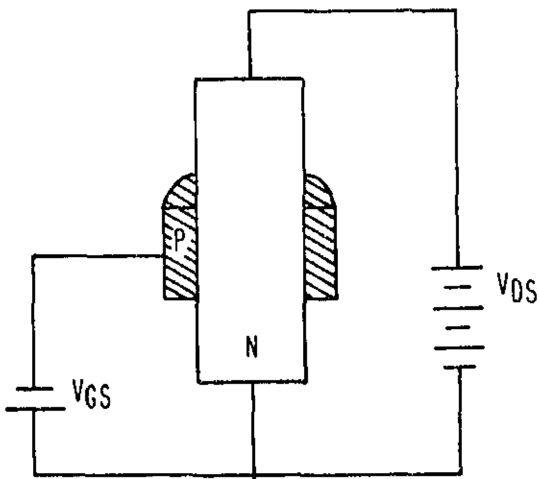


Point 2 corresponds to full penetration o
(*where the two depletion regions meet*).
pinch-off condition. Operation now is in
current region where the drain current re
same level despite the increase in V_{DS}.

5. If the drain-source voltage is made too h
channel junction will undergo avalanche b
causing the current to rise sharply. It
that the device will be damaged if power
is not held to a safe level.

C. Influence of the Gate Potential

1. The resistivity of the channel depends on
drain voltage and gate voltage. The infl
gate on the channel current can be enhanc
necting a negative voltage between the ga
source (*common*), *as shown in figure 4.*
establishes a larger depletion region and
channel resistivity for a given V_{DS}. In
will cause pinch-off at a lower V_{DS}. Thi
the limiting drain current will also be l
gate bias voltage is made high enough, th
current can be reduced practically to zer
activity can be compared with the cut-off
tube's plate current when a high control
applied.



There are three main regions. In the ohmic region th drain current rises significantly with the increase i the drain-source voltage because neither gate potenti nor the channel IR drop have enough influence to caus pinch-off. The drain-source voltage has a significan influence on the drain current, and the output resist ance is relatively low. The second region (pinch-off is one of saturation. The current remains essentiall constant for a large change in V_{DS}. This constant current characteristic means that the output resistan is high, providing favorable operating conditions whe high voltage and/or power gain are desired. The thir region is the breakdown (avalanche) region.

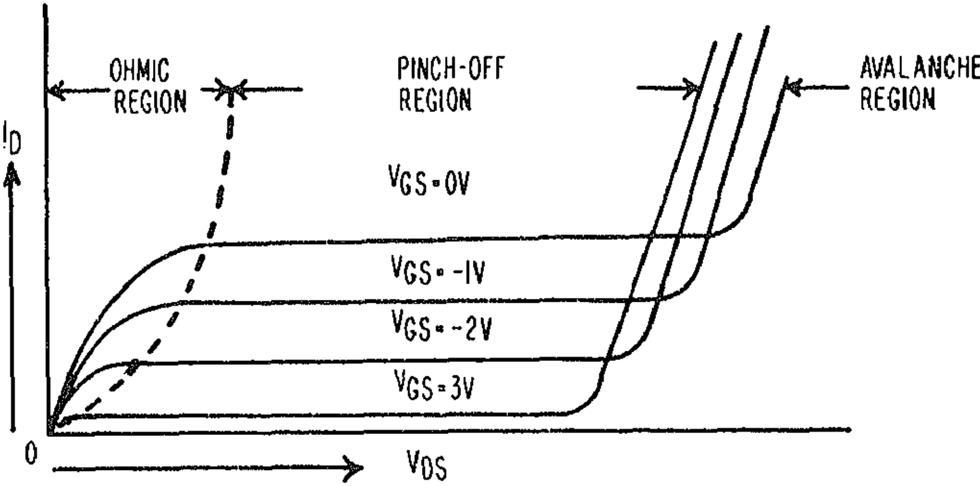


Figure 5 Family of Curves for a Typical N-Channel JFET

As long as the gate-channel junction is reverse biase

There will be corresponding changes in the
of the channel and the movement of charges
channel. Consequently, the drain current
the changes in the gate-source voltage (V_G
control of the channel current (I_D) by V_{GS}
the influence that a grid voltage has on t
the electrons (plate current) between the
the plate of a vacuum tube. To the extent
signal voltage across a high impedance con
output current, a field-effect transistor
a vacuum tube than a bipolar transistor.

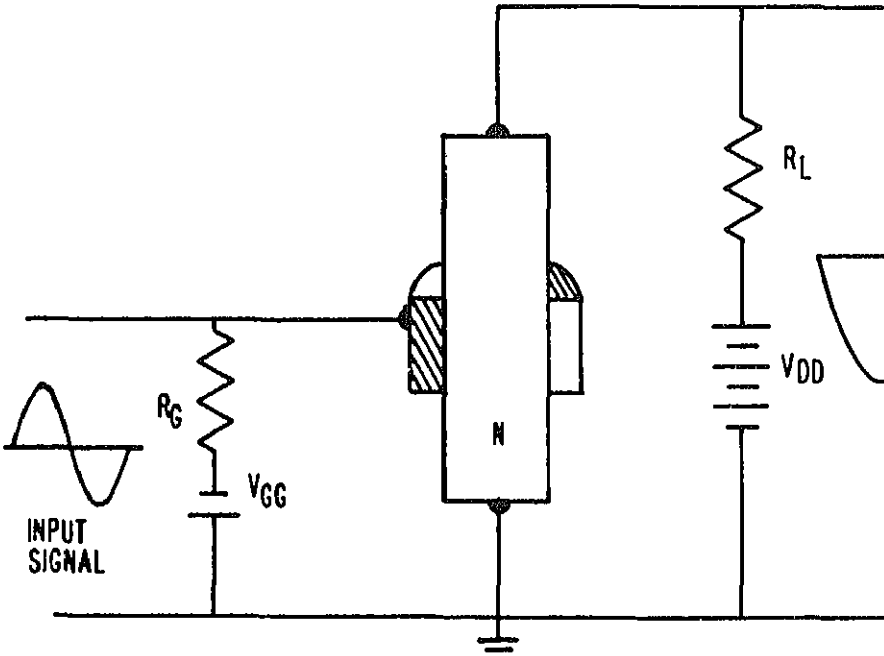
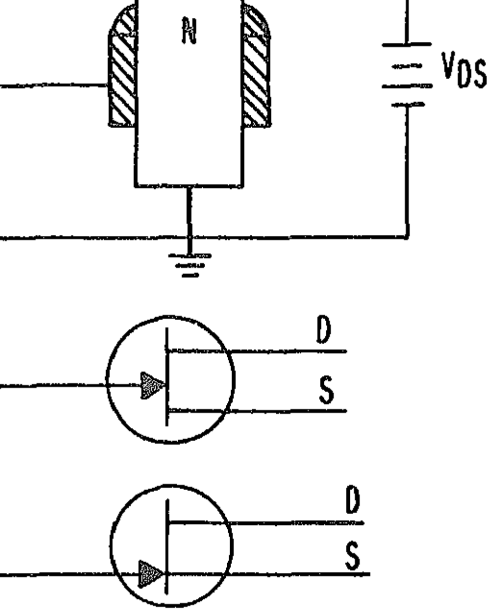


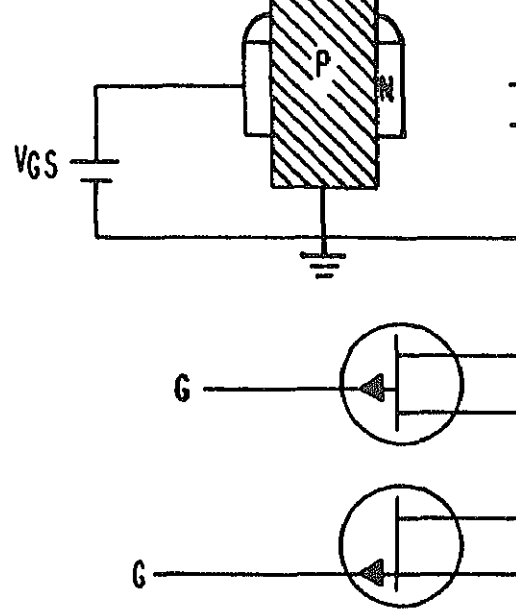
Figure 6 Signal Input to and Output from a

D. JFET Types

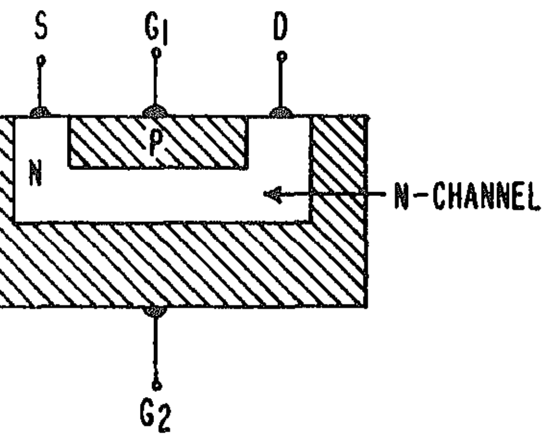
1. Field-effect transistors come in various t
structures. Just as there are PNP and NPN
transistors, there are both N-channel and
JFET's, as seen in figure 7. In a P-chann



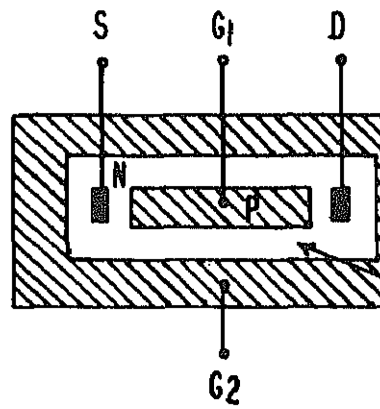
(A) N-CHANNEL



(B) P-CHANNEL



(C) SIDE VIEW (TETRODE)



(D) TOP VIEW (TETRODE)

sistor depends on the motion of both types carriers. For this reason the conventiona is called a bipolar type. The bipolar tra two junctions, one forward-biased and the biased. It is the interaction between ele holes at the emitter junction which result fusion current in the base that propels ch high electric field across the reverse-bia base junction.

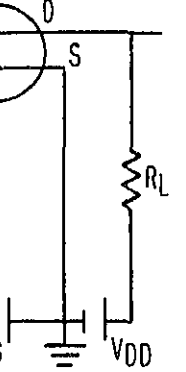
2. It is possible to include two gate element from each other as shown in figures 7(c) a their symbols in figures 7(e) and (f). Th are available for mixing and other circuit such as AGC and d-c feedback, in which a d a-c amplification is to be established. T called dual-gate field-effect transistors. second input is not used, it is normally c the circuit so that its gate-channel junct reverse-biased.

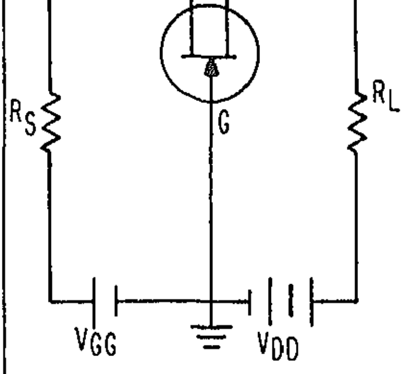
E. Basic Circuit Configurations

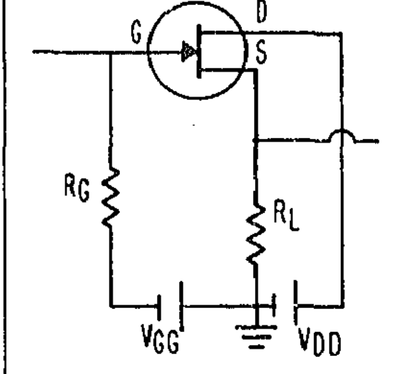
1. Like the vacuum tube and the bipolar trans field-effect transistor can be connected i arrangements (figure 8). Each has its ind characteristics. The common-source connec most widely used. It has a good voltage g input impedance, and a medium-to-high outp Input signal is applied between the gate a and the output signal is developed between the source.

2. Input and output voltages are out-of-phase example, a positive swing of the input to junction FET increases the drain current t channel. The resulting increase of drain through the load resistance causes a decre positive drain voltage. Conversely, a neg the gate voltage decreases the drain curre creases the drain voltage.

3. The common-gate configuration's voltage ga than that of a common-source. Input imped and output impedance is high; therefore, t



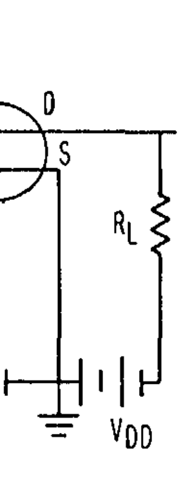


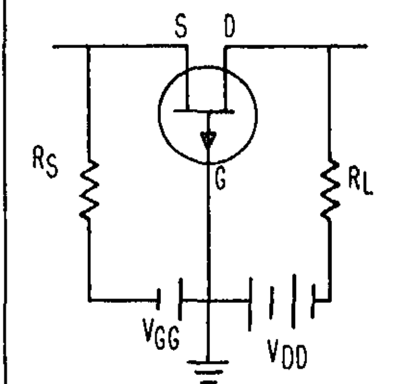


ge gain
impedance
tput imped.
utput
phase

Moderate voltage gain
Low input impedance
Moderate output imped.
Input and output in
phase

No voltage gain
Very high input imped.
Low output impedance
Input and output in
phase





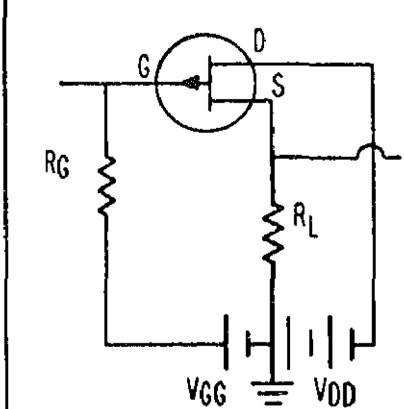


Figure 8 Basic JFET Cirsuits

4. Input and output voltages are in phase. U
channel FET as an example, a swing of the
in the positive direction (same as a negat
the gate voltage) decreases the drain curr
creases the drain voltage. Conversely, a
of the source voltage increases the drain
decreases the drain voltage.

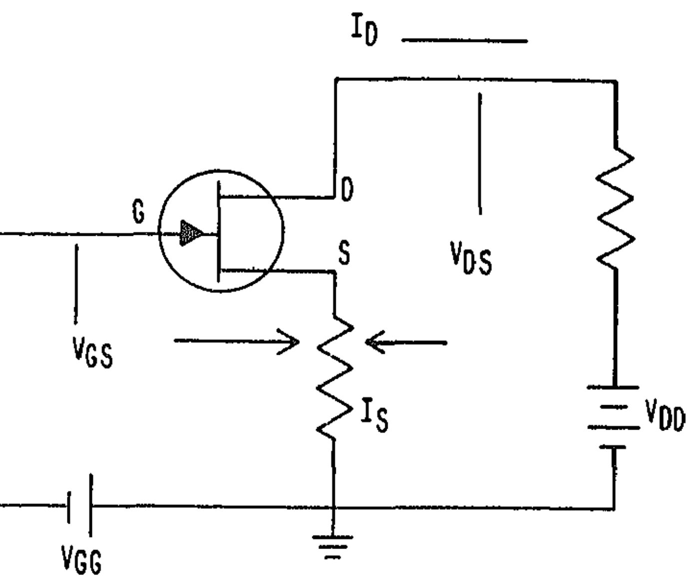
5. The common-drain's (source follower) input
very high, and the output impedance is low
impedance of the common drain can be compa
input impedance of the common-gate. A cur
possible but there is no voltage gain.

6. nput and output voltages are in-phase. F
using the N-channel JFET, a positive swing
age increases the source-to-drain current.
crease causes the source (output) voltage
the positive direction. Conversely, a neg
the gate voltage decreases the drain curre
source voltage.

F. Symbols

1. Standardization of alphabetical and graphi
electronics continues to be a problem for
industries, and engineering societies. Th
solid-state devices has resulted in some s
ization, and certain procedures have becom
accepted. It should be stressed that, alt
now common to use the letter V for voltage
state symbology, the letter E continues to
relation to vacuum tubes.

2. When a current is specified, the first sub
cates the element at which the current is
When a voltage is specified, the first sub
to the element at which the voltage is mea
the second subscript indicates the referen
When no second subscript is used, the volt
ment uses the common (ground) as a referen
conventions of figure 9 are widely observe
present time.



ure 9   Key d-c Voltages and Currents
of a JFET Circuit

s and Specifications

amily of drain characteristics for a typical P-el FET (2N2608) is given in figure 10. Note that rain voltage used is negative. The less positive the greater the magnitude of drain current (I_D). xample, a drain voltage of -10 volts and V_{GS} of volts, I_D is 0.6 milliamperes. If the gate bias duced to +0.2 volts, I_D rises to about 1.4 milli-es. The breakdown voltage is also indicated on the t characteristic curves. This is the point at avalanche occurs on the V_{GS} = 0 curve.

on FET specifications compare the drain current l (ΔI_D), to the gate voltage signal (Δ_{GS}) at a ant VDS. This ratio, $g_{fs} = \frac{\Delta I_D}{\Delta V_{GS}}$ $\Delta V_{DS} = 0$ is

d the small signal common-source forward trans-ctance. This is similar to gm in vacuum tubes. cates the control that gate-source voltage has on current and has a value that ranges from 35 to 0 umhos. If the drain-to-source resistance (r

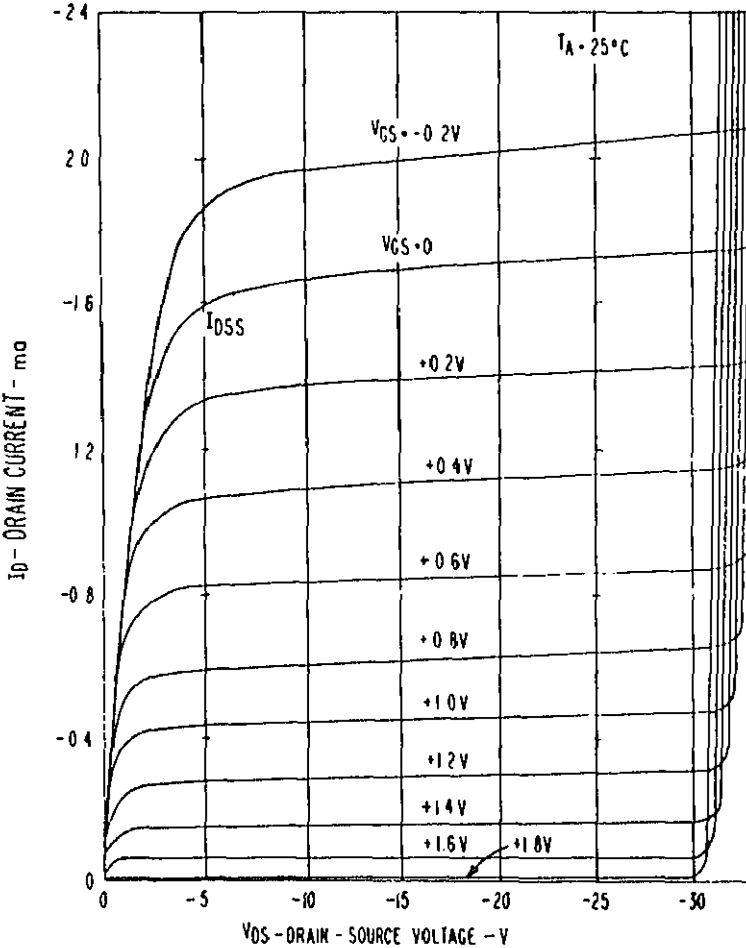
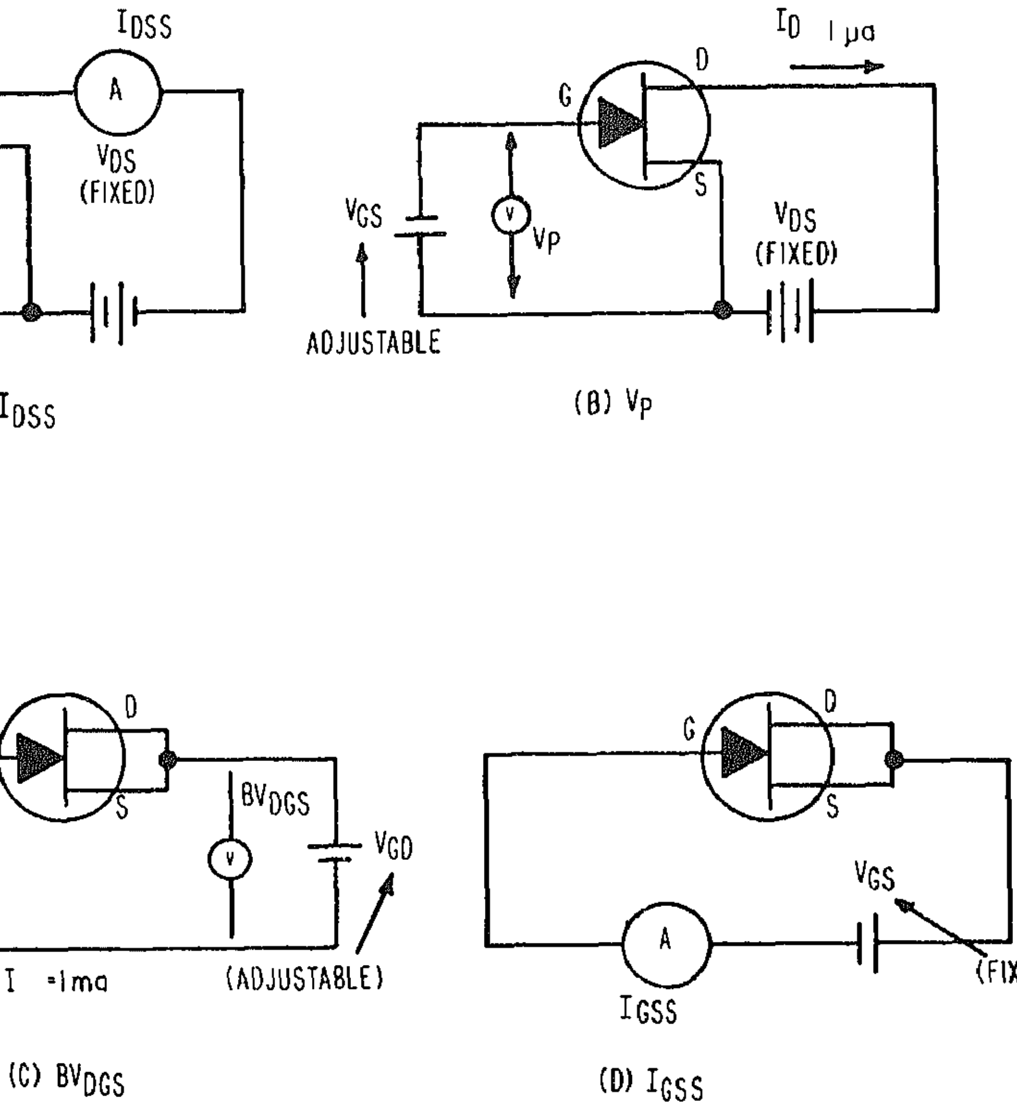


Figure 10   Typical JFET Output Characterist
for the 2N2608

3. An important parameter of a FET is the zer



igure 11 Measuring Key Fet Parameters

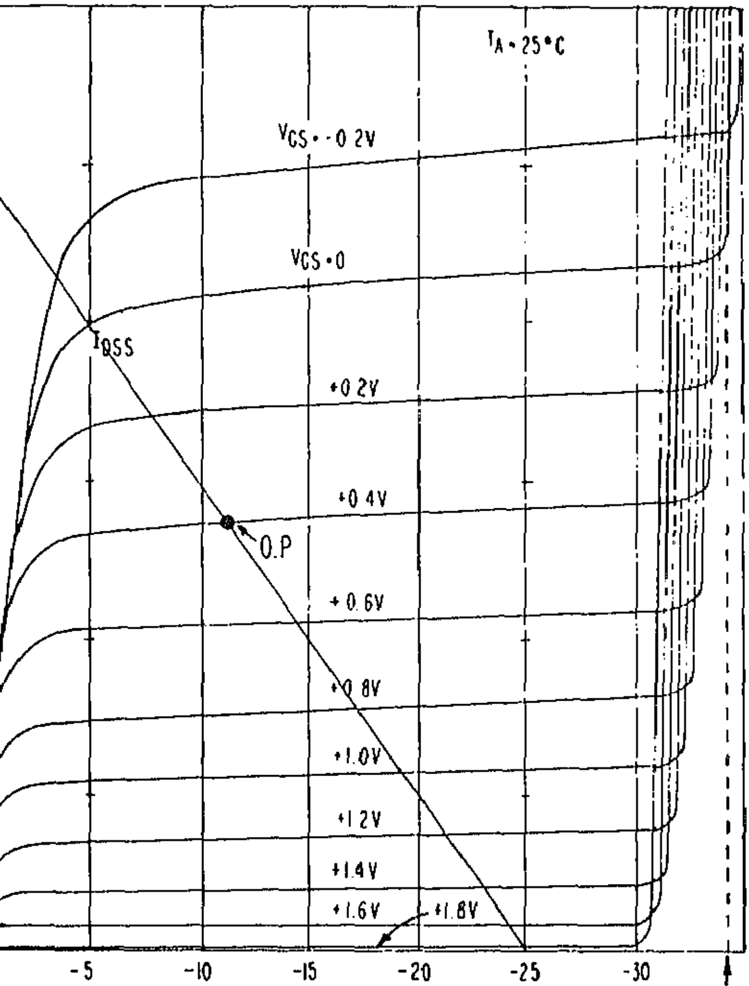
gate-bias voltage (V_{GS}) at which the drain current l be reduced to practically zero for a specified in voltage (V_{DS}) is known as the gate-source pinch- voltage (V_P). Some insignificant value of drain

	Parameter	Units	Min
SS	Gate-Source Cutoff Current at: V_{GS} = 30V V_{DS} = 0	mA	
SS	Gate-Source Cutoff Current at: V_{GS} = 5V V_{DS} = 0 T_A = 150°C	μA	
GDS	Gate-Drain Breakdown Voltage at: I_G = 1μA V_{DS} = 0	Volts	30
SS	Drain Current at Zero Gate Voltage: V_{DS} = -5V V_{GS} = 0	mA	0.90
	Gate-Source Pinch-off Voltage at: V_{DS} = -5V I_D = 1 μA	volts	1
s	Small-Signal Common Source Forward Transconductance at: V_{DS} = -5V V_{GS} = 0 f = 1kHz	μmho	1000
ss	Gate-Source Capacitance at: V_{DS} = -5V V_{GS} = 1V f = 140 kHz	pF	12
	Noise Figure at V_{DS} = -5V V_{GS} = 0 f_o = 1M		

are certain maximum ratings which, if exceeded, result in the destruction of the transistor. A y of the key parameters and specifications for 3 as furnished by the manufacturer are shown in 1.

g a Load Line

line can be drawn (figure 12) on the FET's teristic curves.



$\overline{\Delta V_{GS}}$ $\overline{.4}$

2. At the operating point, the transconductar about 1375 µmhos. Using the formula

$A_V \approx g_{fs} R_L$: $A_V \approx (1375 \times 10^{-6})(12.5 \times 10$

The slight discrepancy in this case is bec error in reading the curves; however, the mation is as accurate as most electronic c

I. Noise Considerations

The noise content of a FET is low in compariso tube or a bipolar transistor. The three sourc in a field-effect transistor are: The gate-le shot noise, thermal or resistance noise that r the agitation of the charge carriers in the ch low-frequency noise (1/f noise).

J. Frequency Response

1. Low power junction FETs have a gate-to-dra tance (C_{gd}) ranging from 1 to 100 pF. Thi increases as the drain-to-source voltage i approaches the pinch-off voltage. As a re capacitance (C_{gd}) the "Miller effect" occu tion FET's.

2. A regular (bipolar) transistor's low imped input tends to shunt a large portion of th sistor's high impedance internal feedback emitter. The Miller effect in regular tra therefore, not as great as in FETs where t signal at the gate, like the internal feed is usually also of high impedance.

3. The Miller effect in FETs can be reduced b the drain to source voltage, reducing the input impedance or with a feedback circuit semiconductor's internal feedback.

4. Theoretically, junction FETs should be abl frequencies up to 1 GHz, although the maxi

an be made to operate well as common-source iers at frequencies of several hundred megahertz.

e Effects

on FETs, like regular transistors, are normally ed by changes in temperature (T_A). Measurements te that their pinch-off voltage (V_p) usually in- at about 0.2% per 8°C.

gh FET PN junctons are affected by temperatures, te current stability of silicon FETs approaches se current stability of bipolar silicon tran- s. Provided the circuit's gate-to-source re- ce (R_G) lies between 1 and 10 megohms.

posing effects of temperature change in JFETs in a linear decrease in I_{DSS} with increasing ature, causing the current to decrease about 0.6% . This drift can be reduced by operating the FET level of I_D.

e of JFETs with lower pinch-off voltages also s I_D drift. Measurements show that FET's having V pinch-off experience no temperature drift when ing at their normal I_{DSS} and g_{fs}.

ardization--In a previous lesson, it was shown ransistors of the same type have exactly the same stics. The same problem exists with JFETs. of the same type have I_{DSS} and g_{fs} ratings that much as 2 to 1.

and Disadvantages:

uld be apparent that the primary advantages of are:

ry high input impedance.

w noise characteristics.

gh their voltage gains are relatively low, once a pedance point occurs in a circuit, the bipolar

The reader must be aware that, although th
characteristics are temperature sensitive,
near as sensitive to T_A variations as the
transistor.

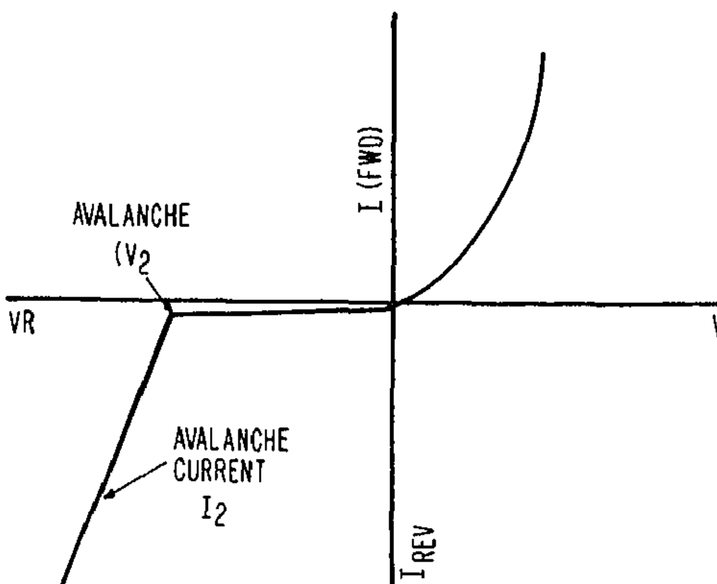
II. AVALANCHE DEVICES

A. Avalanche is defined as a cumulative process b
charged particles collide with and ionize the
through which they are traveling.

B. As long as the current-handling capacity of th
not exceeded during the avalanche process, som
characteristics can be utilized.

1. Zener Diode

A zener diode is a PN-junction diode that
heavily doped than the average diode. It
to operate in the reverse bias breakdown,
region without damaging the junction. Sir
diode operates in the reverse-bias directi
it operates on minority carriers.



breakdown (VZ) occurs is determined by the type of semiconductor material used, the type of doping material used, and the actual doping level of the zener diode.

Once the diode goes into the avalanche region, the voltage across the diode will remain almost constant The reverse-bias potential accelerates the minority carriers to such a velocity that they physically dis lodge other carriers from the crystal lattice. The result is a very large current flowing in the zener diode. If the voltage applied to the junction de- creases, the acceleration of the carriers will decrease, which results in less current through the diode. With less current flow, the zener impedance increases and the voltage across the diode remains constant.

The constant voltage characteristics of the zener di (in the avalanche region) are particularly useful ir voltage regulator circuits.

Figure 14 is a basic voltage regulator circuit emplo ing a zener diode as the regulating component.

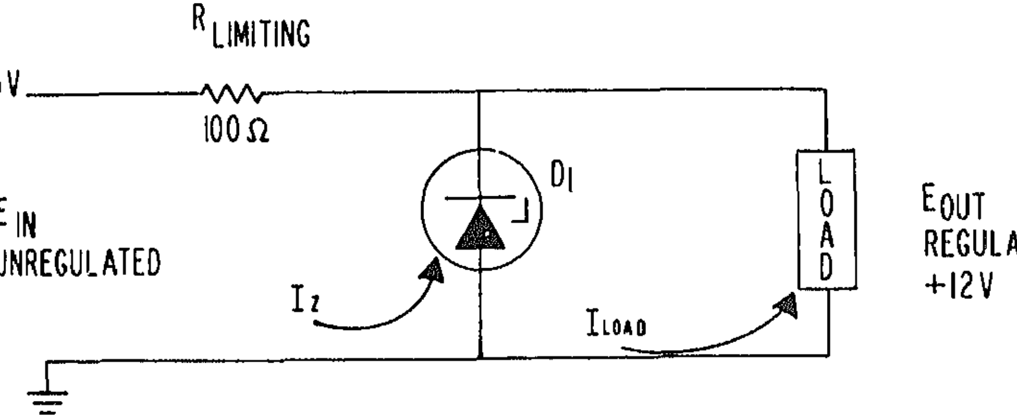


Figure 14

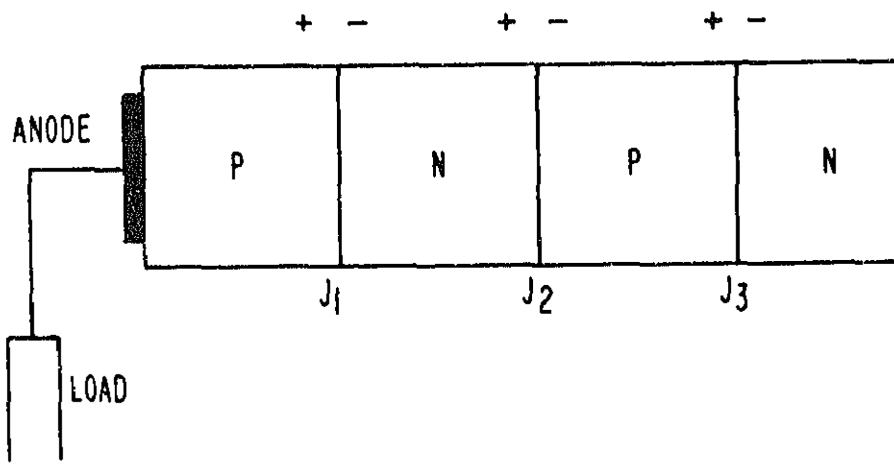
rent flow through $R_{limiting}$ decreases output returns to +12 volts.

b. If the unregulated voltage increases, suppied to the zener diode will incre increased voltage (VZ) will cause an IZ. When IZ increases, the voltage d $R_{limiting}$ will increase, thus returni regulated output to +12 volts.

2. Four-layer didoes (PNPN)

a. A PNPN diode is a 4-layer, 3-junction operates in the avalanche mode.

b. As shown in figure 15, the layers are doped P- and N-type semiconductor mat ohmic contacts to the P-type and N-ty The ohmic contact to the P-type regio the anode, and the contact to the N-t called the cathode. Notice that the and N-regions are floating.



said to be "OFF" or blocking, which represents a high resistance between anode and cathode.

With J2 reverse-biased, only minority carriers flow through the internal P- and N-areas. The negative voltage on the N-type cathode injects electrons into the internal P-type area where they flow as minority carriers, and the positive voltage on the P-type anode injects carriers into the internal N- type area where they also flow as minority carriers.

As can be seen in figure 15, as the applied voltage (V_F) is increased, more injected holes from the P-type anode will diffuse through the internal N-type material and be controlled by the internal P-type material. The internal P-type material becomes more positively charged (contains more holes), thus increasing the forward-bias on J3.

At the same time J3 is increasing its forward-bias, the N-type cathode is injecting more carriers into the internal P-type material which diffuse into the internal N-type region which becomes more negatively charged (more electrons) increasing forward-bias at J1.

As J1 and J3 increases their forward bias, their junction resistance decreases and more of the applied voltage (V_F) is felt at the reverse-bias junction J2, increasing the depletion region at J2.

As the depletion region at J2 increases, the effective N and P areas are reduced.

Figure 16 depicts the condition now existing; i.e., the increased depletion region at J2 and the reduced efective areas of the internal N and P-type materials. As the external voltage (V_F) continues to increase, the carriers crossing the depletion region gain velocity as they are swept across the junction. When the velocity the carriers gain while crossing the junction is great enough, free carriers are produced in the internal N- and P-type

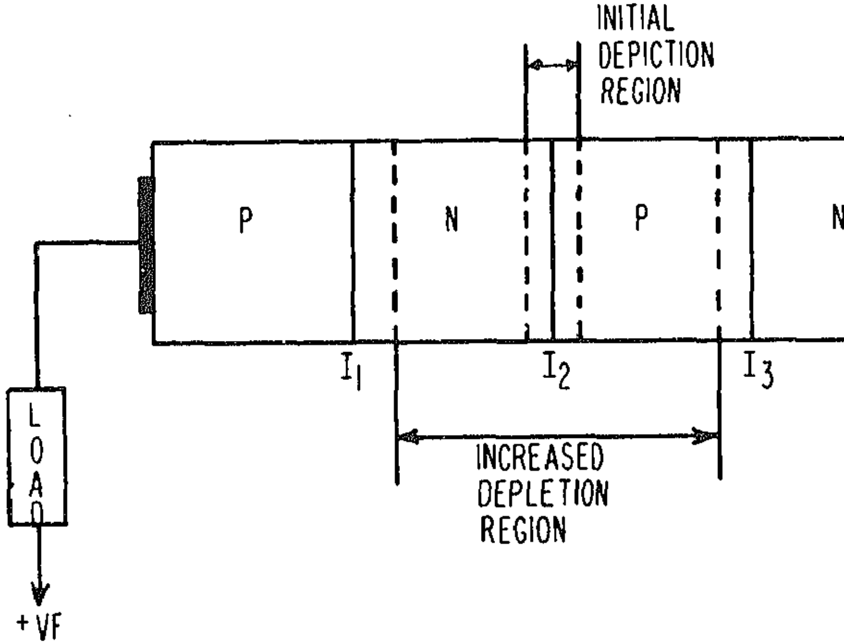
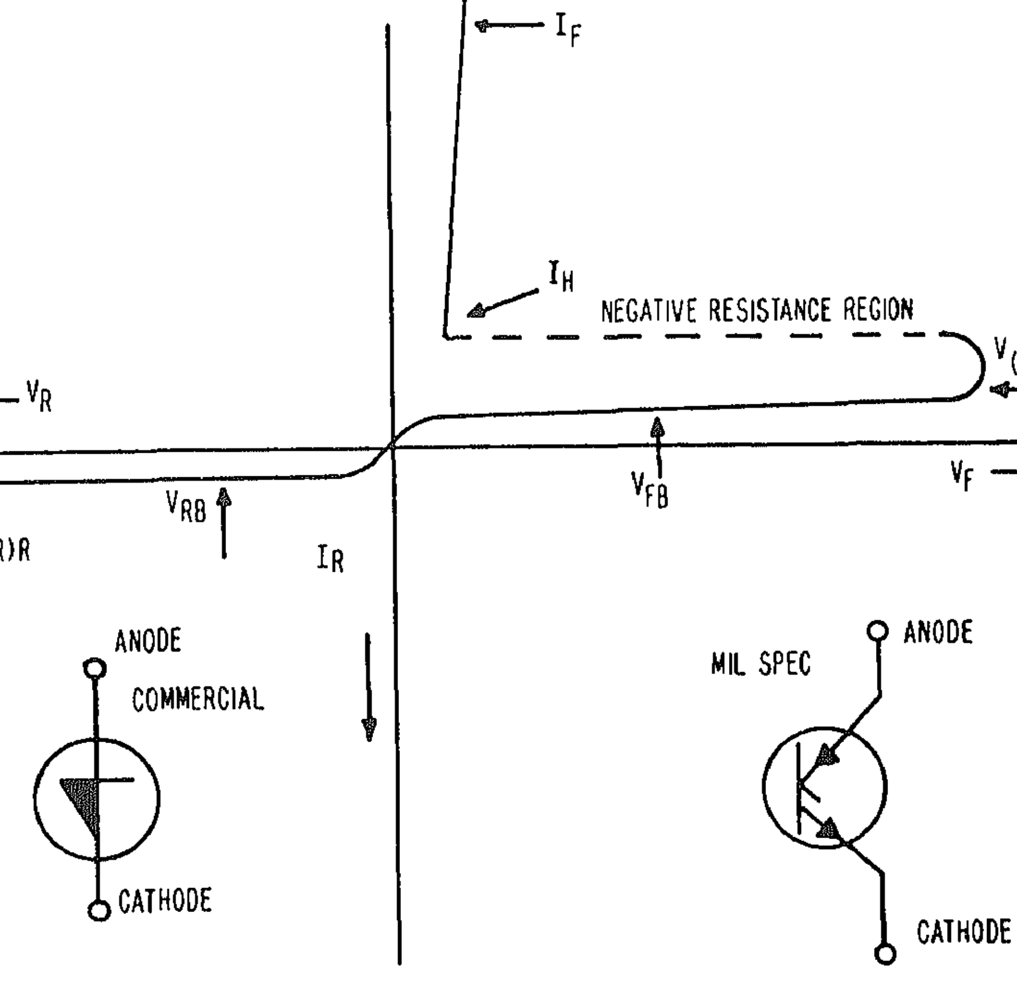


Figure 16

j. This process is accumulative and anode
starts increasing rapidly because of t
carriers generated. Avalanche soon oc
current must be limited by external se
ance or else the device will destroy i
device is said to be switched "ON" and
low resistance between anode and catho

k. The PNPN device thus acts as a switch.
high resistance, very low current flow
low resistance, heavy current flow. W
device is turned on, a specific amount
(I_F) must be maintained to keep it on.
rent is specified as holding current,
current rating that must be considered
current I_L. The latching current rati
a value of anode current, slightly hig
holding current, which is the minimum
quired to sustain conduction immediate
device is switched ON. In other words



PNPN CHARACTERISTIC GRAPH

Figure 17

. The applied voltage V_F, anode positive to cathode, that results in a small current flow is called the forward blocking voltage, V_{FB}. As the forward voltage is increased, a sudden increase in current is apparent as the device switches "ON." The minimum voltage necessary to turn the device on is

i.e., as reverse-bias, V_R, is increased a
will occur at the reverse breakdown point
$V_{(BR)R}$. The PNPN switch can be destroyed
reverse-bias avalanche region and should
operated with reverse-bias between anode
cathode.

o. PNPN switches are used for trigger device
low-cost sweep generators and timers.

p. Figure 18 is another sweep-generator circ
a PNPN switch.

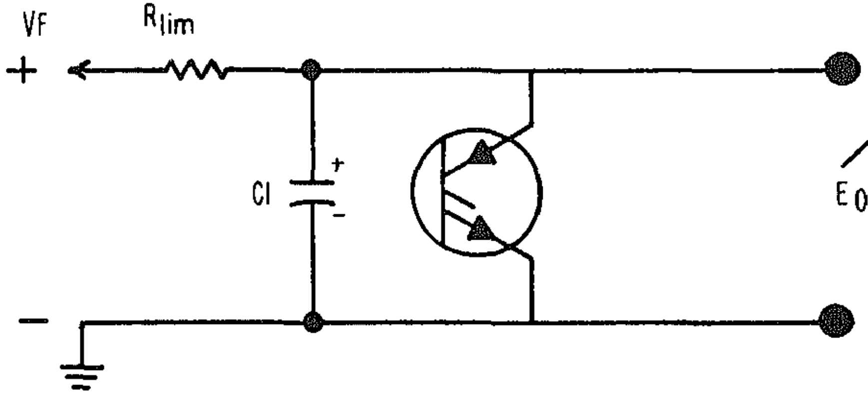


Figure 18

When V_P is applied to the anode of the PN
the capacitor starts charging toward V_F.
voltage across the capacitor reaches $V_{(BF}$
diode turns ON and discharges the capacit
sawtooth waveform is thus produced across
diode. R_{lim} limits the current to a safe
with C1 determines the rate of firing.

3. Silicon Controlled Rectifiers (SCR)

a. Basically, the SCR is a PNPN structure wi
ohmic contact made to the internal P-type

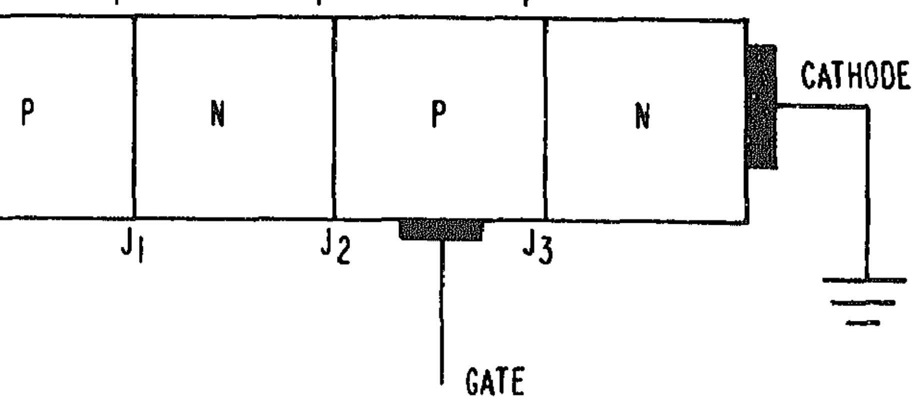


Figure 19

ne additional lead is called the gate and aids in ne "turn-on process."

ne SCR is normally operated with $V_F \ll V_{(BR)F}$, nere $V_{(BR)F}$ represents the forward breakover oltage, as was the case with the basic PNPN evice. With the gate open, the SCR will be "OFF" r in the blocked condition. When a positive oltage is applied to the gate, current will flow nto the gate (I_{GT}).

ne current flow (electrons) in the gate is in- ected from the N-type cathode; however, many njected carriers will diffuse through the in- ernal P-type material to the internal N-type aterial. The internal N-type material now takes n a negative charge (excess electrons) increasing ne forward bias on J1. The increased forward-bias n J1 increases injected holes through J2 from the node.

process just described and also includ
commercial and Mil-Spec symbols for th

g. Notice that as I_{gate} is increased, tur
(breakover) occurs at lower values of
quite an advantage over the basic PNPN
there was no control over the breakove

h. Also apparent in figure 20 is the fact
acts as a bistable switch; i.e., "ON"
V_F is a positive voltage and V_{gate} is
positive.

i. The SCR is the solid state equivalent
eous thyratron tube which is switched
voltage pulse on its control grid whic
tube. The SCR on the other hand recei
pulse on its gate which aids in the "a
process in much the same manner as a t
Like the thyratron's grid, the SCR's g
control once the device turns on. The
turned off in the same manner that the
was.

(1) Reducing the anode-cathode to zero

(2) Driving $I_F < I_H$.

(3) Forcing commutation.

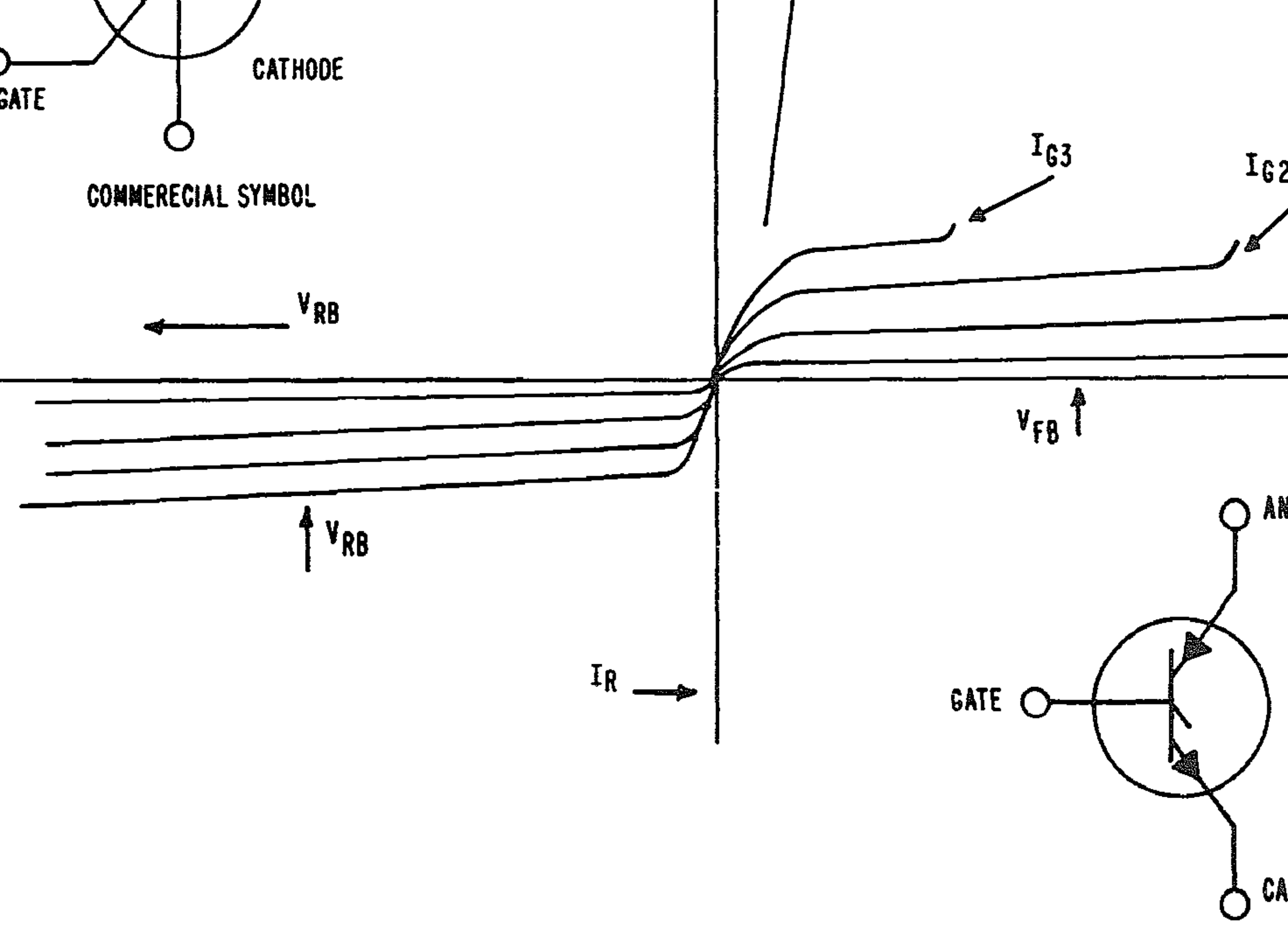
j. The main advantage of the SCR is its a
control heavy load currents with light
(gate) currents. Currently SCR's have
cations among them, being; motor speed
heating controls, and ignition systems

k. As stated earlier, the SCR may be turn
several methods:

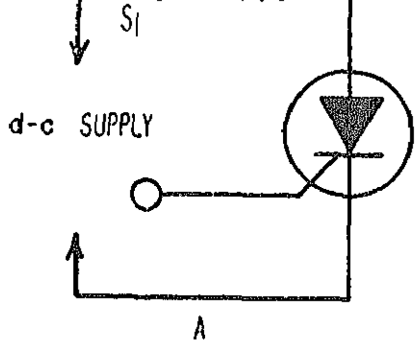
(1) Reducing anode current to zero.

(2) Driving I_F to $< I_H$.

(3) Commutation.



GATE
CATHODE
COMMERECIAL SYMBOL
V_RB
I_G3
I_G2
V_FB
V_RB
I_R
GATE



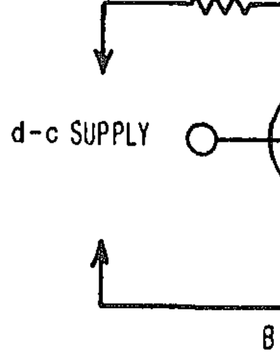


Figure 21

Figures 21a and 21b will definitely "fit
for conditions (1) and (2) above; however
be difficult to operate the switch at a v
frequency or with any appreciable current
tation is the most often used "turn off"
employed. This method switches current f
energy source to force current through th
the reverse direction. There are six dis
classes of commutation.

(1) Class A - Self-commutated by resonati
load.

(2) Class B - Self-commutated by an LC ci

(3) Class C - C or LC switched by another
carrying SCR.

(4) Class D - C or LC switched by an auxi

(5) Class E - An external pulse sound for
commutation.

(6) Class F - A-c line commutation.

1. As class F, a-c line commutation is the m
turn-off technique used; it will be the m
analyzed. Figure 22 will be used in the

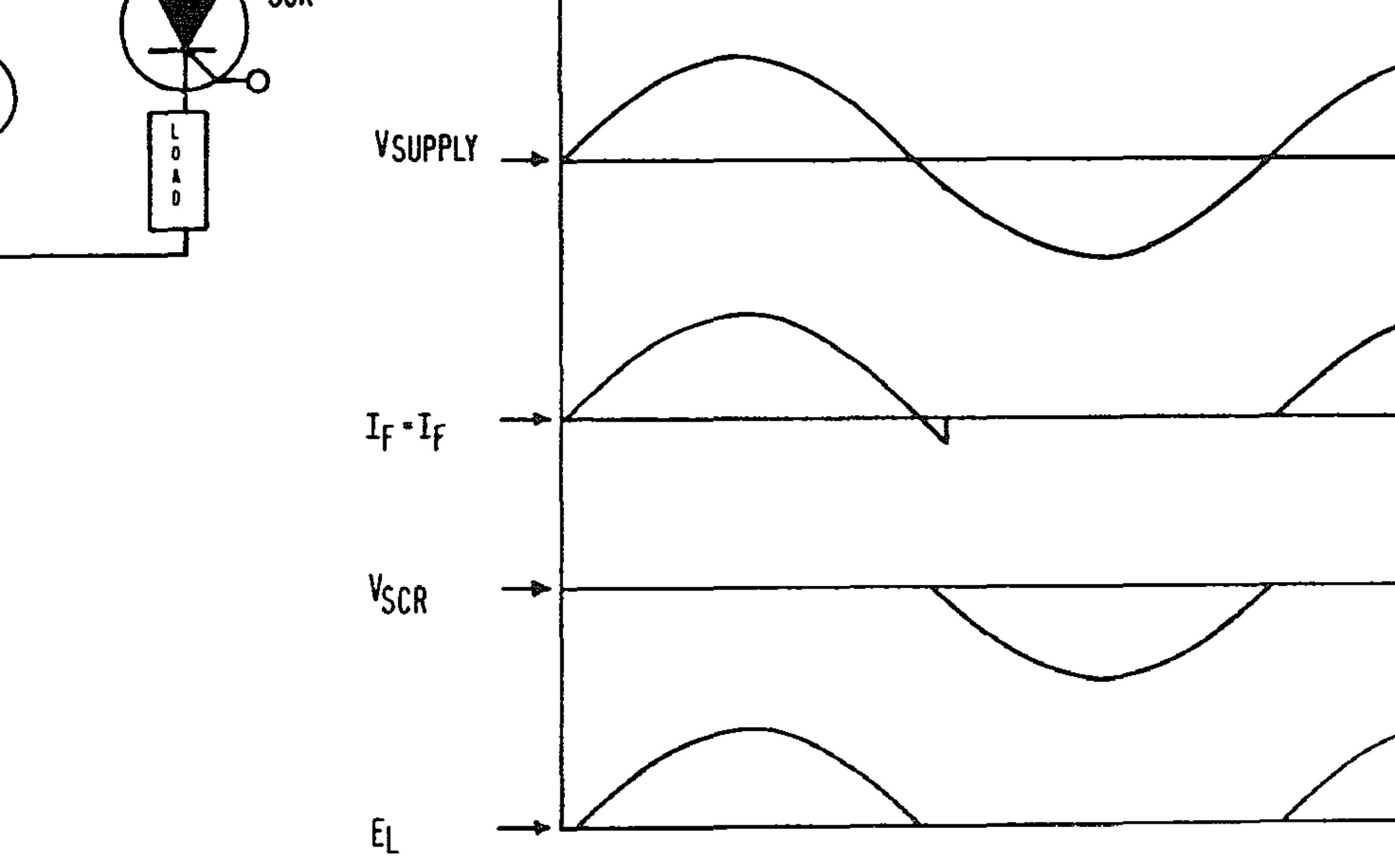


Figure 22

II. UNIJUNCTION TRANSISTORS

A. The unijunction transistor (UJT) is basically with two contacts and a PN junction.

B. Figure 23 shows the construction of an UJT and symbol.

1. The two ohmic contacts made to the base (s are called B_1 and B_2 (N-type material). B potential or common side and B_2 is the hig or voltage supply side. B_2 will be biased respect to B_1 (V_{B2B1}).

2. The PN junction formed is the emitter whic positive in respect to B_1.

a. R_{BB} is the interbase resistance betwee with typical values ranging from 4 kΩ

b. Figure 23A depicts the condition exist emitter base junction with a voltage a B_2B_1 leads (V_{B2B1}) and the emitter vol equal to zero.

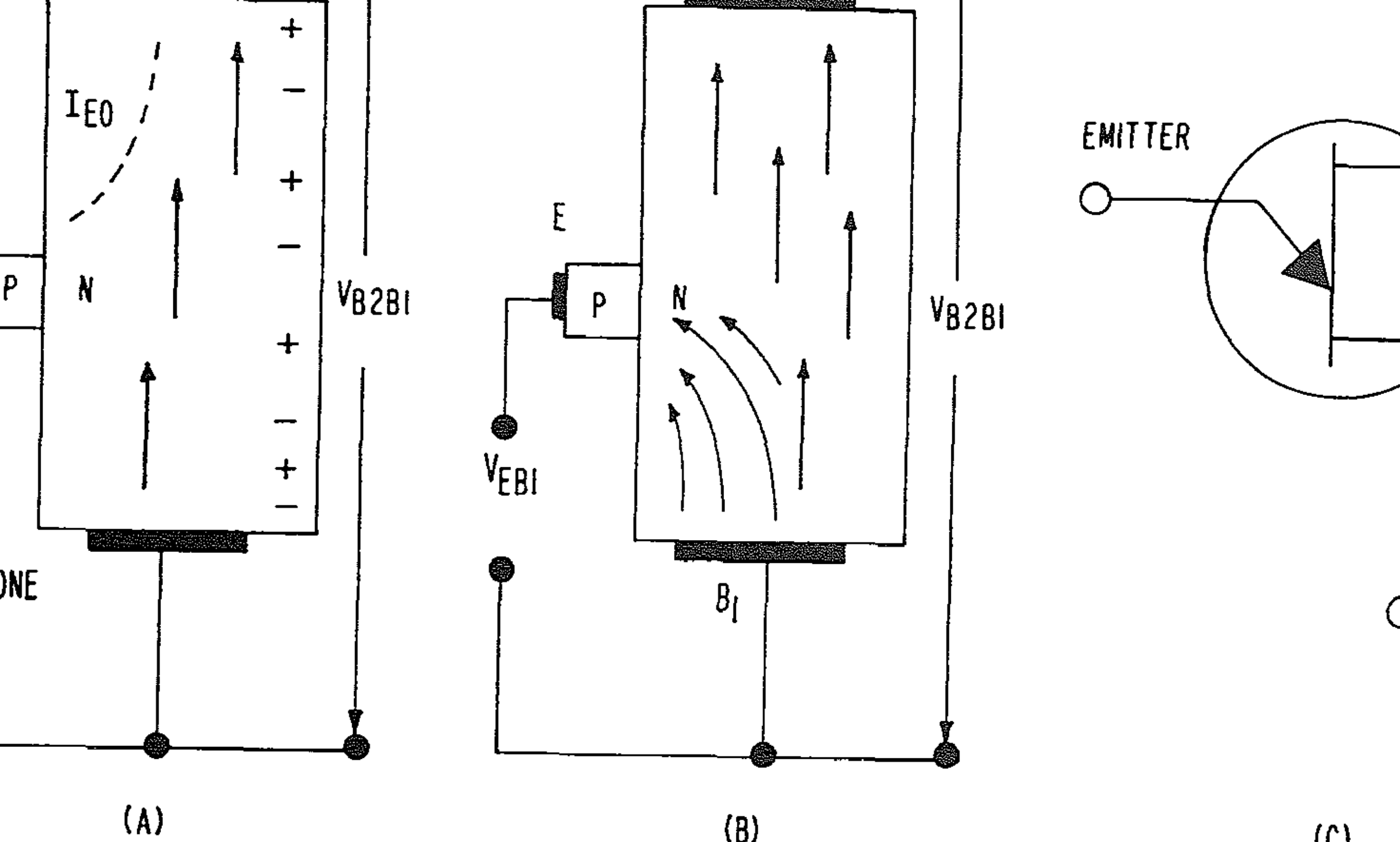
c. With V_{B2B1} applied, R_{BB} develops volta throughout the N-type silicon bar. Th opposite the PN junction, between B_2 a some positive value.

d. Under these conditions, the PN junctio biased and only a small amount of leak (I_{EO}) will flow in the emitter lead. flow in the device will be essentially and B_1.

e. As shown in figure 23B, as the emitter is increased, positive in respect to B V_{EB1}, the PN junction will become forw

(1) The emitter injects holes into the where they are swept toward B_1.

(2) Electrons from B_1 combine with the holes increasing I_E (emitter curre



Unijunction Transistor
Figure 23

4. Thus, the unijunction transistor has many of
acteristics of a gas thyratron. Until the c
voltage (V_{EB1}) reaches a certain value (V_p),
is reverse-biased and essentially cut off.
the critical value is exceeded, the emitter
becomes forward-biased and emitter current i
considerably.

5. A simplified equivalent circuit for the unij
transistor may be developed as shown in figu

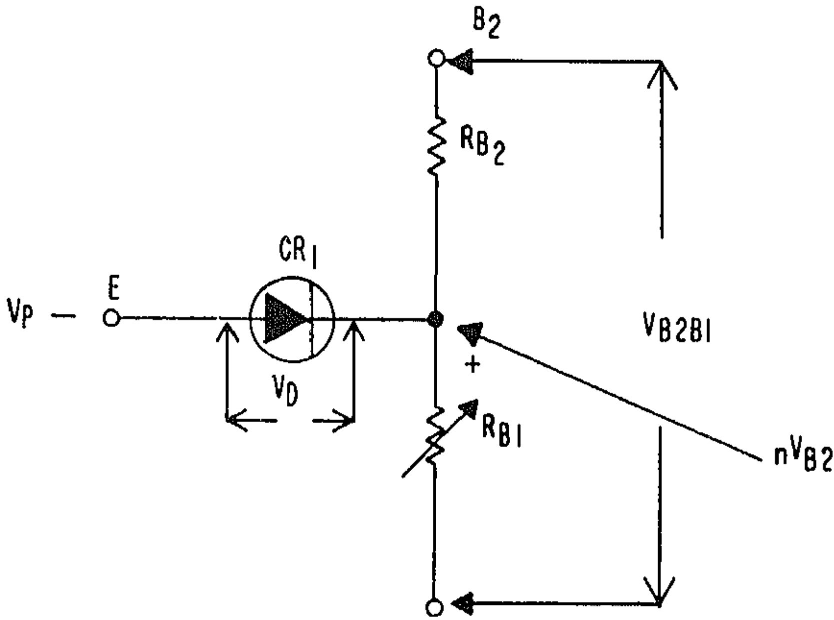
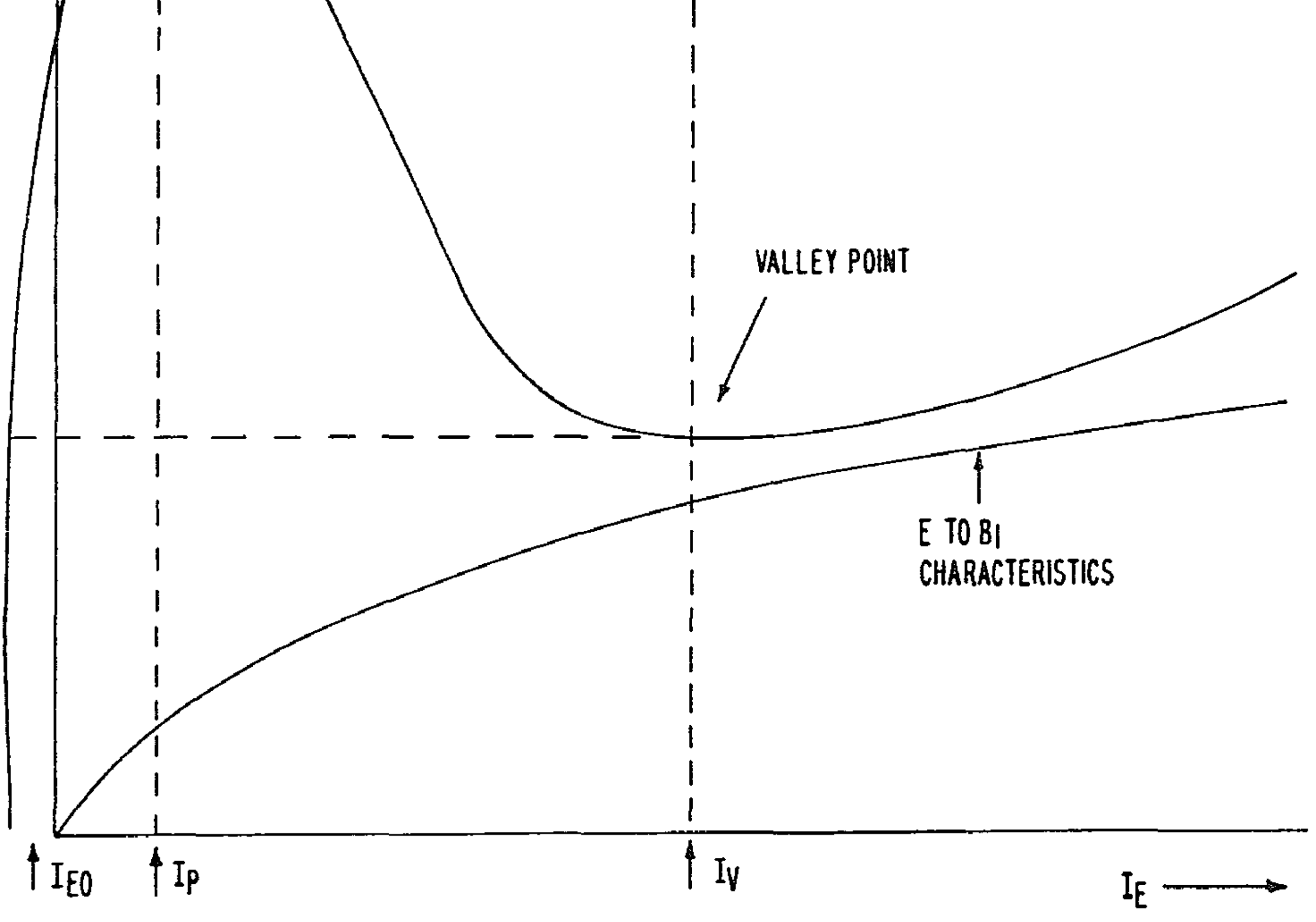


Figure 24

Diode CR_1 represents the emitter-bar PN jun
RB_1 representing the resistance of base 1 a
representing the resistance of base 2. R_{B1}
as variable since it does vary as a functio



VALLEY POINT
E TO B1
CHARACTERISTICS
IE0
IP
IV
IE

is called the intrinsic standoff ratio and
the percentage of the voltage V_{B2B1} develo
R_{B1}. The manufacturer of the UJT supplies
eter in his specification sheet (typical v
from 0.51 to 0.82).

7. Also shown in figure 24 is a voltage drop
diode CR_1 V_D. This voltage will be presen
static condition because of I_{EO}.

8. In order to turn the UJT on, the emitter v
be positive with respect to ηV_{B2B1}. Thus,
$+ V_D$. For example:

Given: $V_{B2B1} = 10$ volts
2N2646 $\eta = .51$
Characteristics $V_D = .5$ volts

Find: The minimum voltage required to tu
UJT (V_p).

Solution: $V_p = \eta V_{B2B1} + V_D$
$V_p = (.51)(10V) + .5\ V$
$V_p = 5.6$ volts

C. A typical characteristic curve of a unijunctio
is shown in figure 25. This curve has three d
regions. Region 1 is the cutoff region, where
is reverse-biased. As the voltage applied bet
emitter and B_1 rises, the current (I_E) rises t
the total current seldom exceeds 10 µA (I_{EO}) R
when the applied voltage reaches the point mar
this point, the UJT "fires" with a large incre
rent and a decrease in the voltage drop betwee
B_1. This is the negative resistance region, a
feature which gives the UJT its unique propert
shall see presently. Eventually there is a po
called the minimum, or valley point, beyond wh
device behaves as a positive resistor. That i
current increases slowly with voltage. This r
called the saturation region. The UJT switche
cutoff to the saturation region quite rapidly
the highly unstable negative resistance region

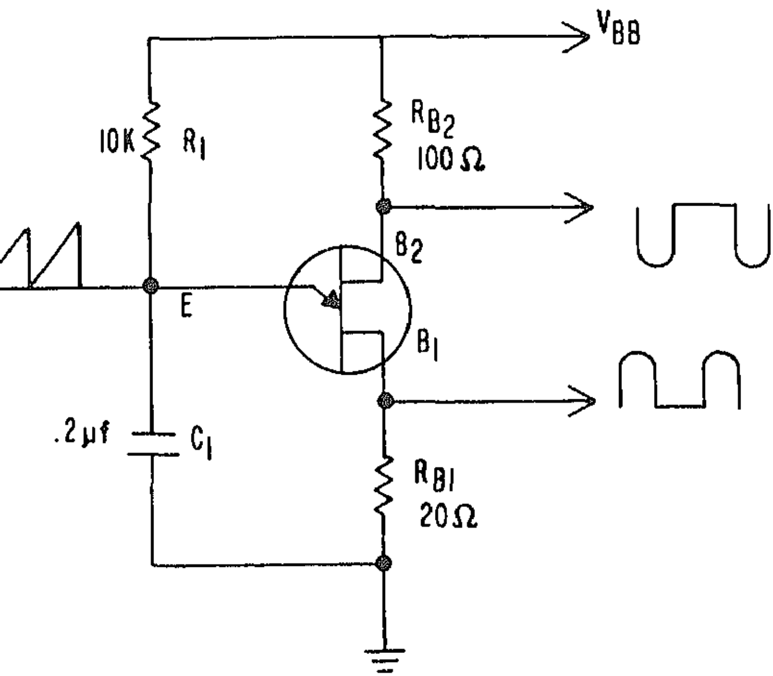


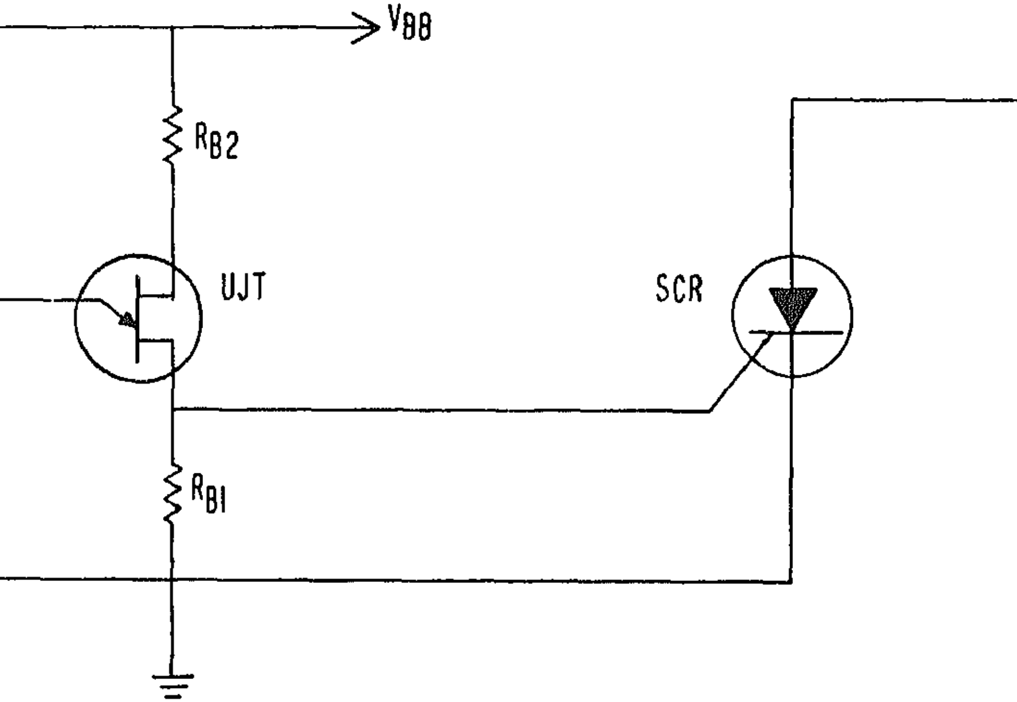
Figure 26

he power supply (V_{BB}) through R_1, it will slowly ge until enough voltage develops across C_1 to ard-bias the emitter junction (V_P). At this point, unijunction transistor "fires." C_1 now discharges dly through R_{B_1} and the low resistance of the ter - B_1 junction. With C_1 discharged, the tran- or returns to its nonconducting state, and the e repeats itself.

vaveform developed in this circuit are also shown gure 26. The voltage across C_1 is a sawtooth possessing a slow rise and a rapid descent. At time of firing, the current through the entire con bar rises developing a positive pulse at the of R_{B_2} and a negative pulse at the bottom of R_{B_1}. the extreme simplicity of this circuit, requiring

Figure 27 is another typical UJT trigger as used to c
an SCR.

1. R_{B_1} develops the positive trigger pulses necessar
   the SCR.



UJT CONTROL OF AN SCR

Figure 27

c Circuits, NAVSHIPS 0967-000-0120

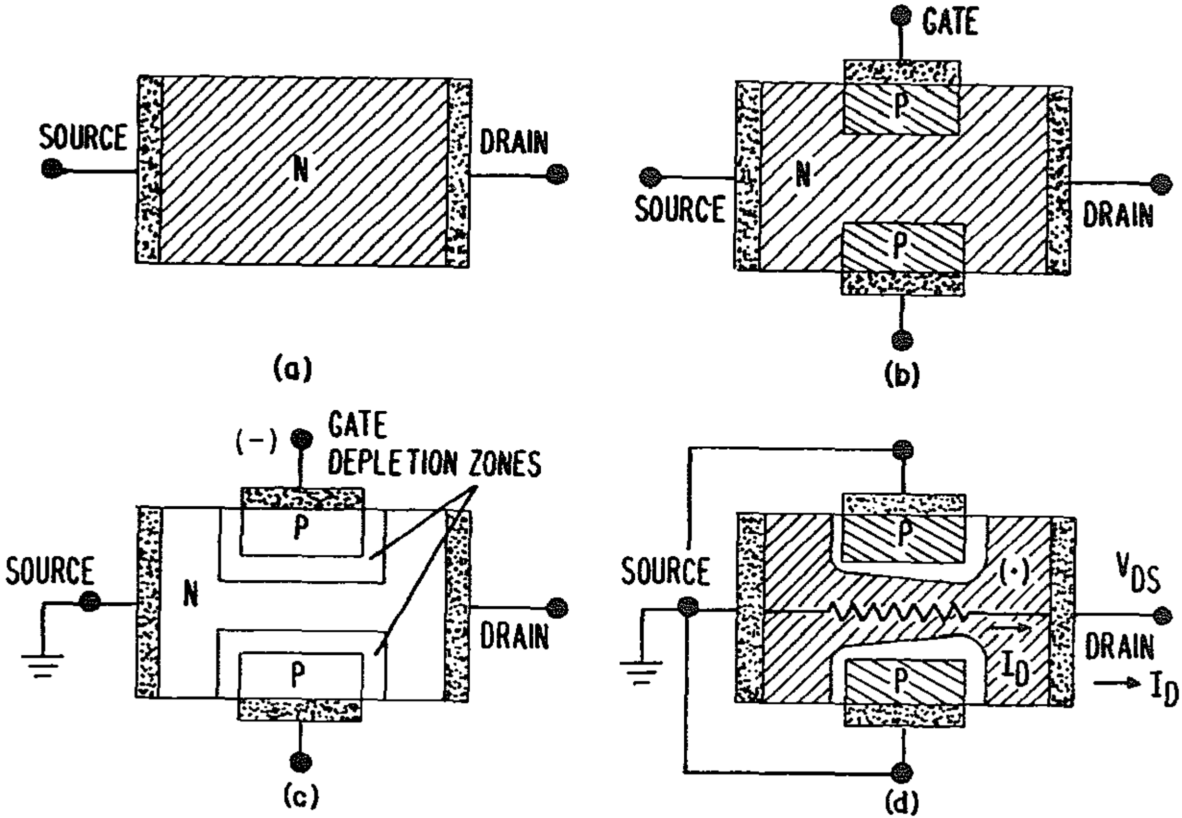
Kiver, Transistor and Integrated Electronics.
ll Book Company, Inc., 1972, Fourth Edition.

. Manera, Solid State Electronic Circuits for
ng Technology, McGraw-Hill Book Company, Inc., 1973.

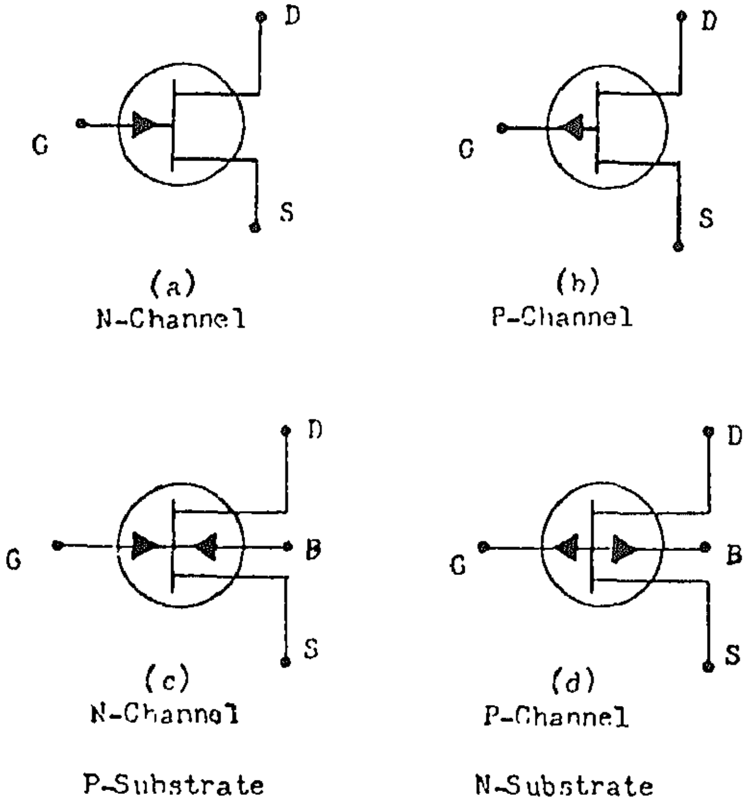
Malvino, Ph.D., Electronic Principles, McGraw Hill
any, Inc., 1979, Second Edition.

CLINE

ion Field-Effect Transistors



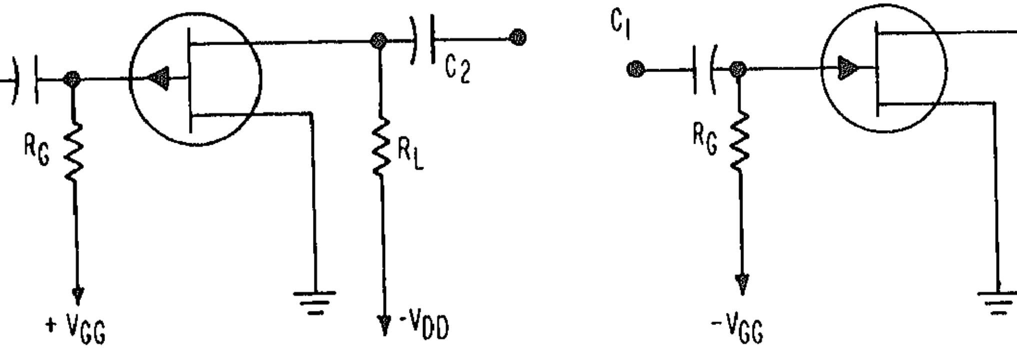
DEVELOPMENT OF JUNCTION FIELD-EFFECT TRANSISTORS



JFET SYMBOLOGY

Figure 4

ology



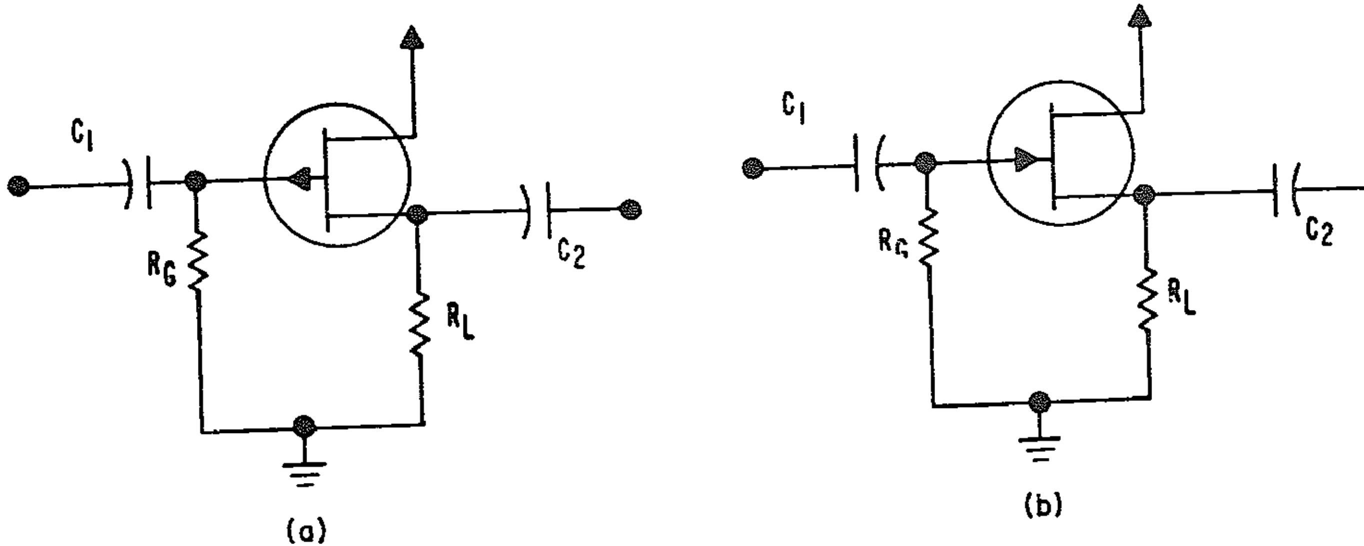
(a)

P-CHANNEL

(b)

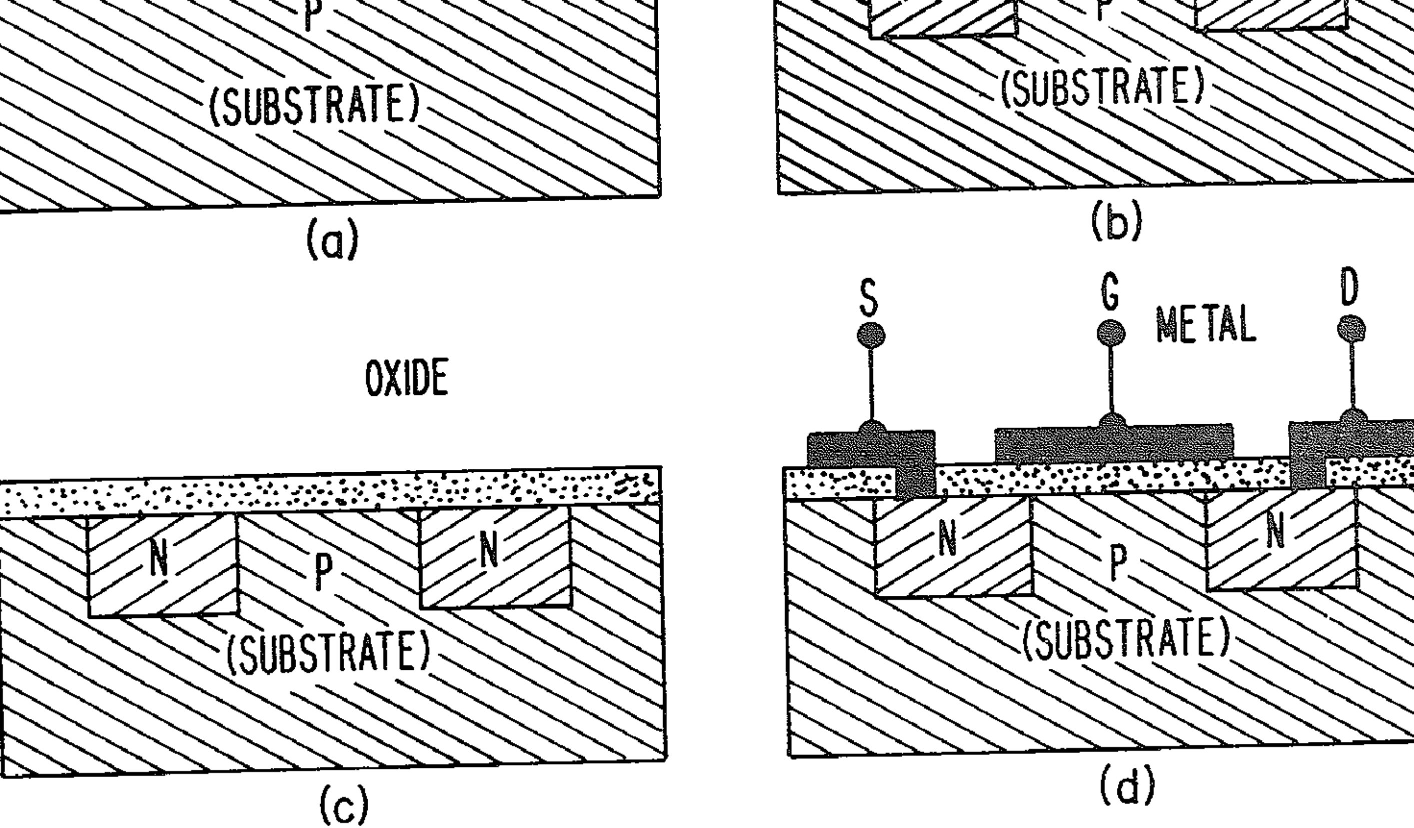
N-CHANNEL

JFET COMMON SOURCE AMPLIFIER



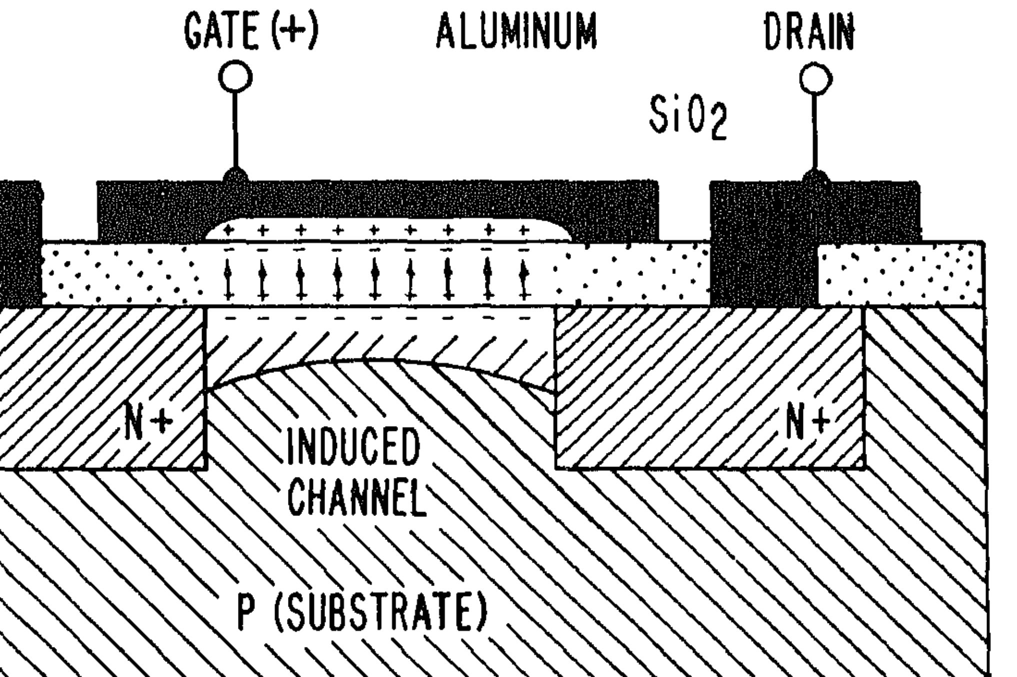
JFET CD AMPLIFIERS

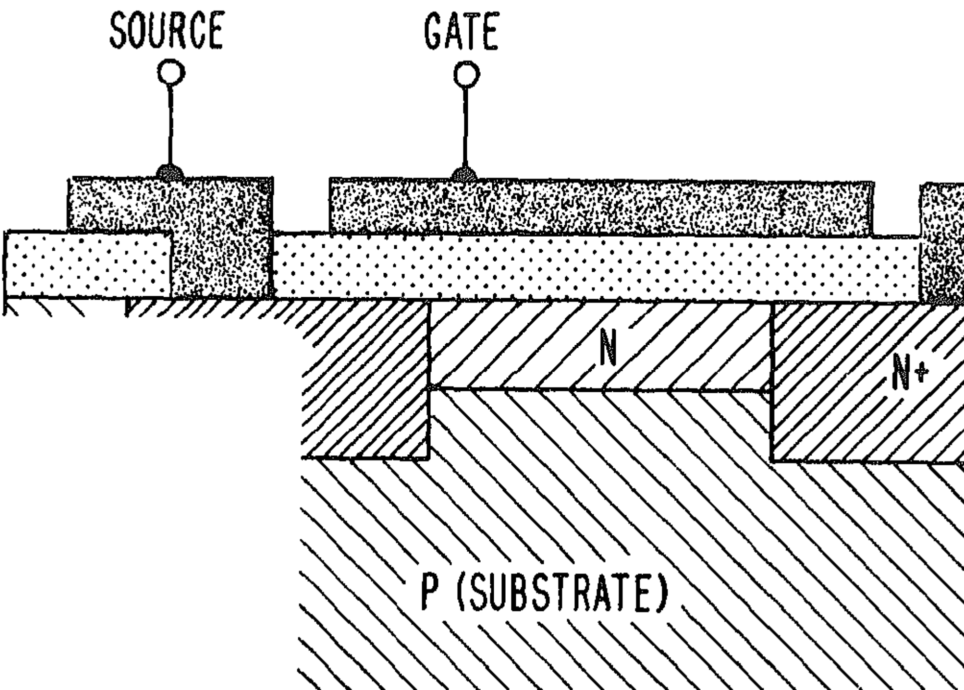
Figure 6

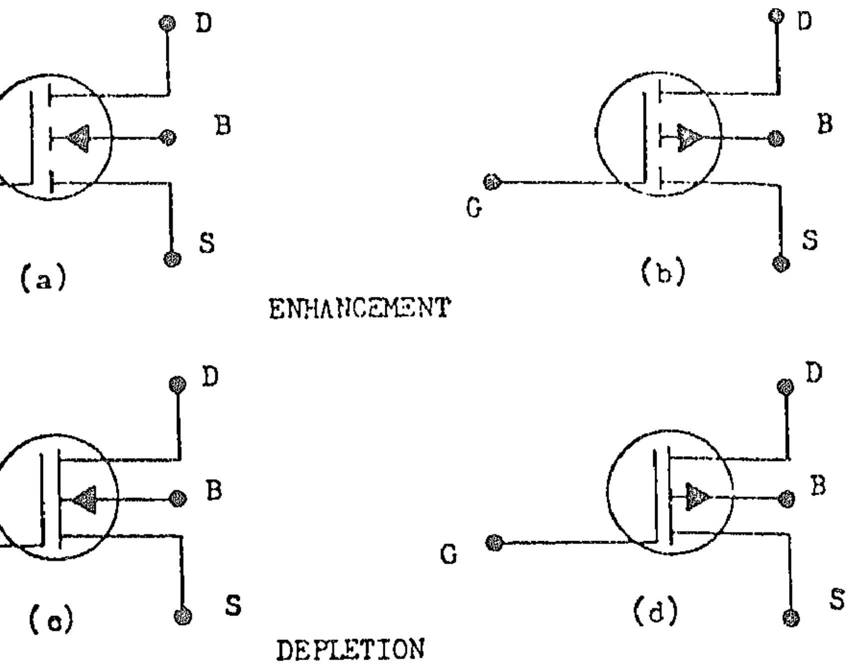


ENHANCEMENT MOSFET CONSTRUCTION

Figure 8


GATE (+)
ALUMINUM
DRAIN
SiO2
N+
N+
INDUCED
CHANNEL
P (SUBSTRATE)


SOURCE
GATE
N
N+
P (SUBSTRATE)



MOSFET Symbols

Figure 11

VI. Avalanche devices

A. Zener Diodes

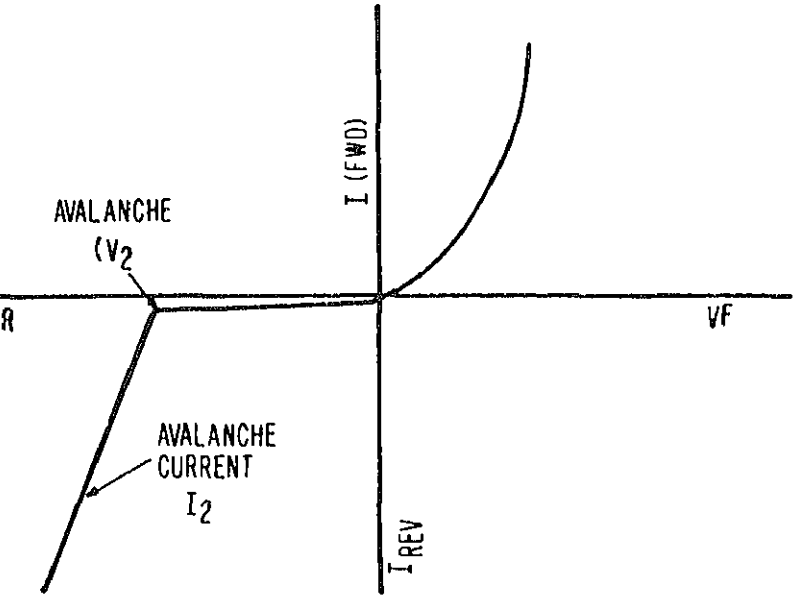


Figure 12

Diodes

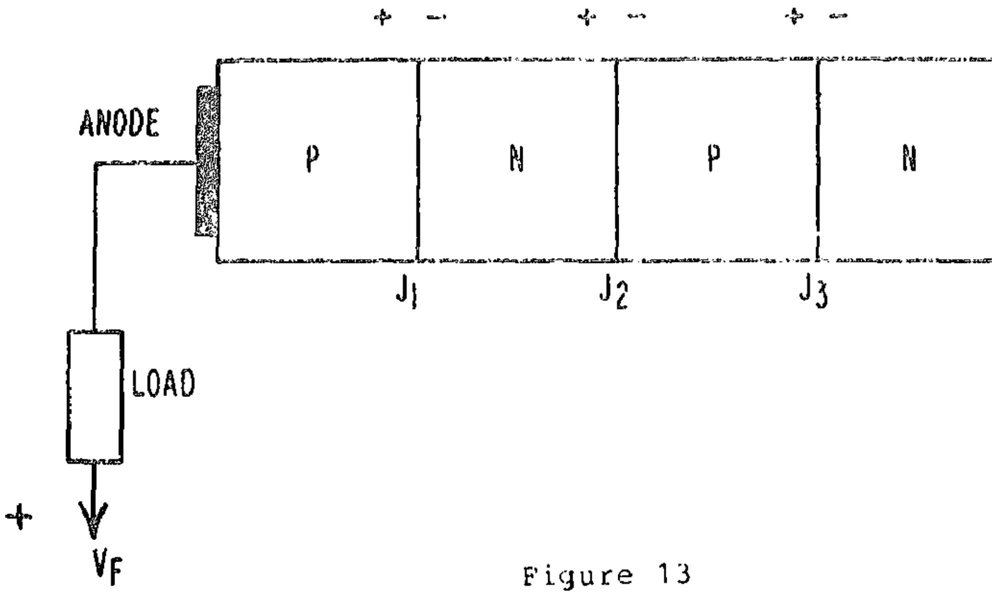
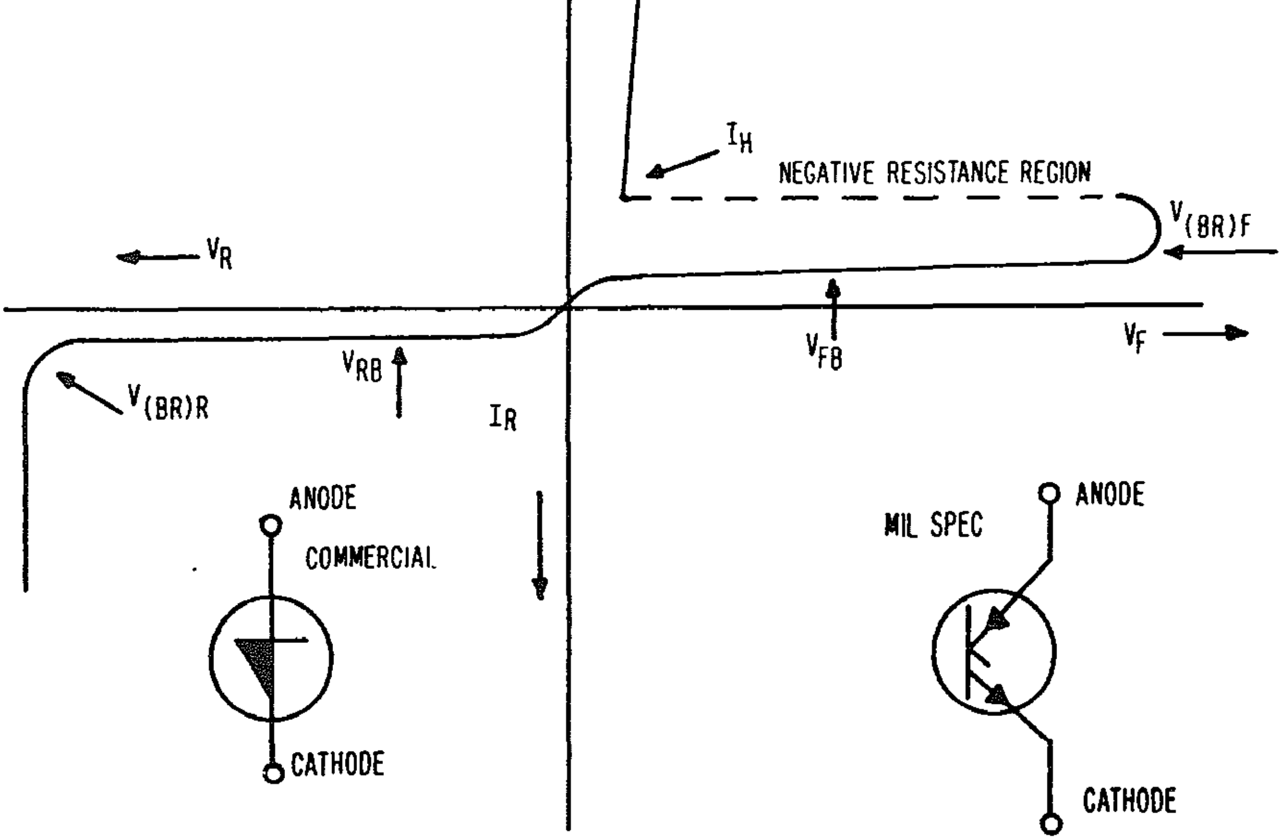


Figure 13



PNPN CHARACTERISTIC GRAPH

Figure 14

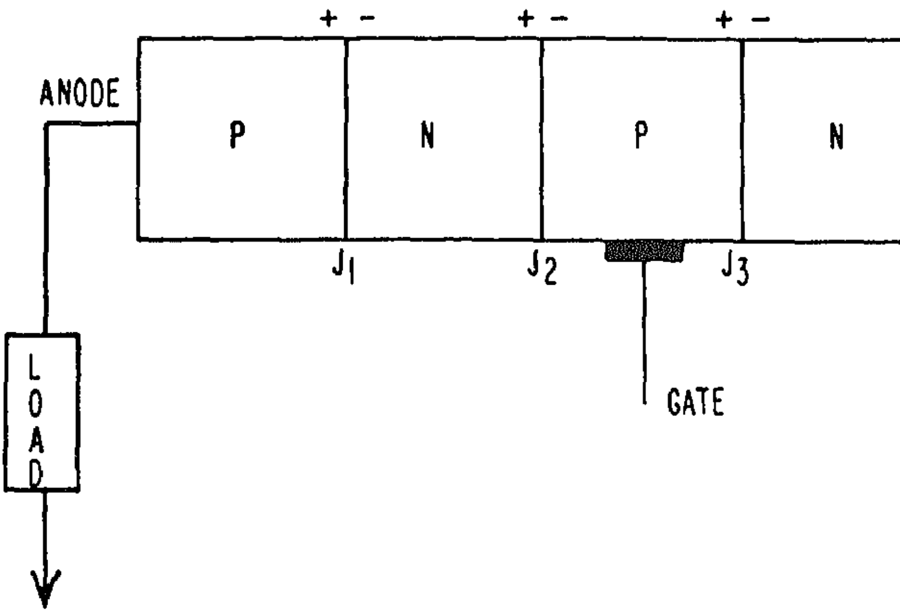
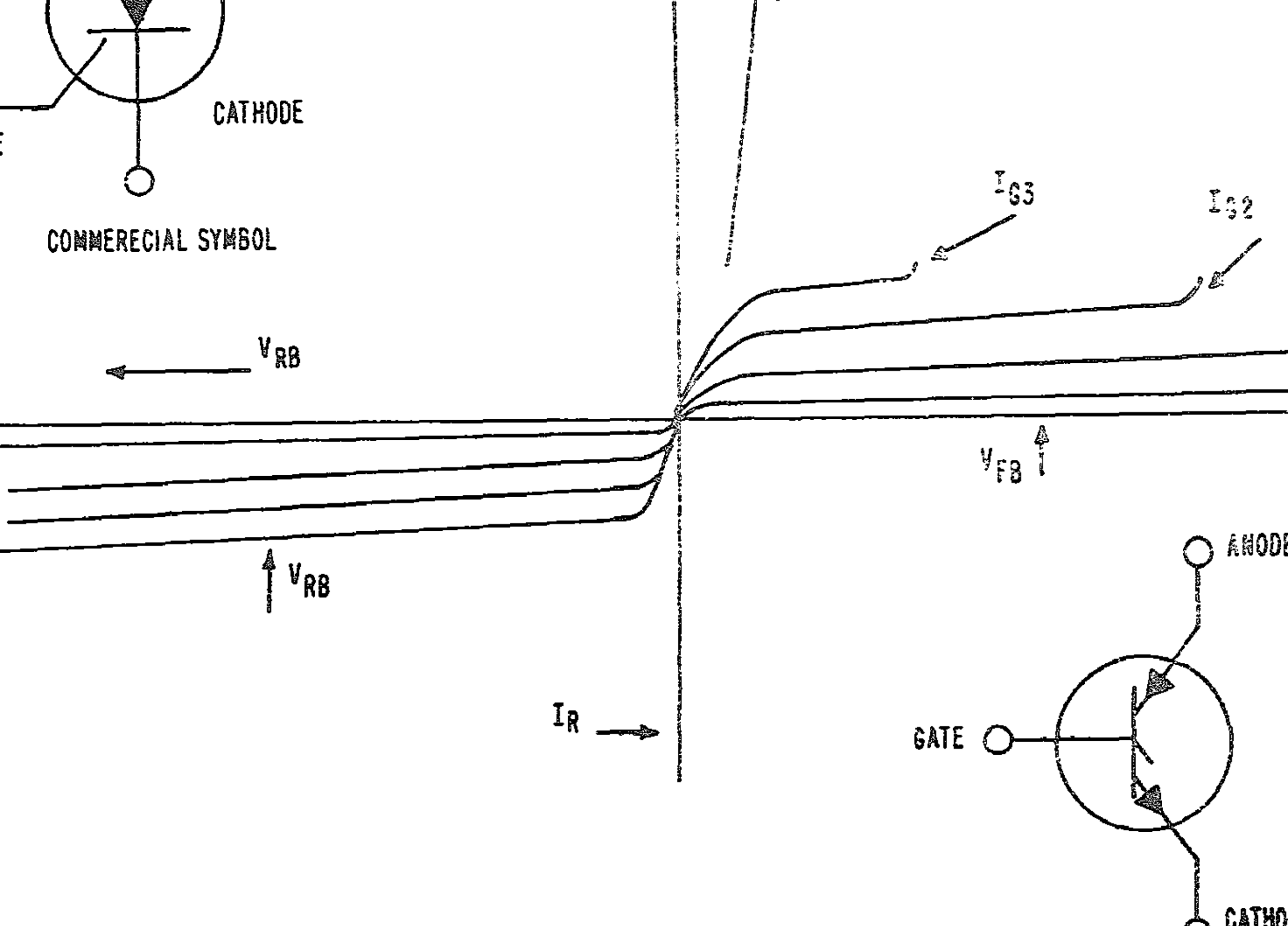
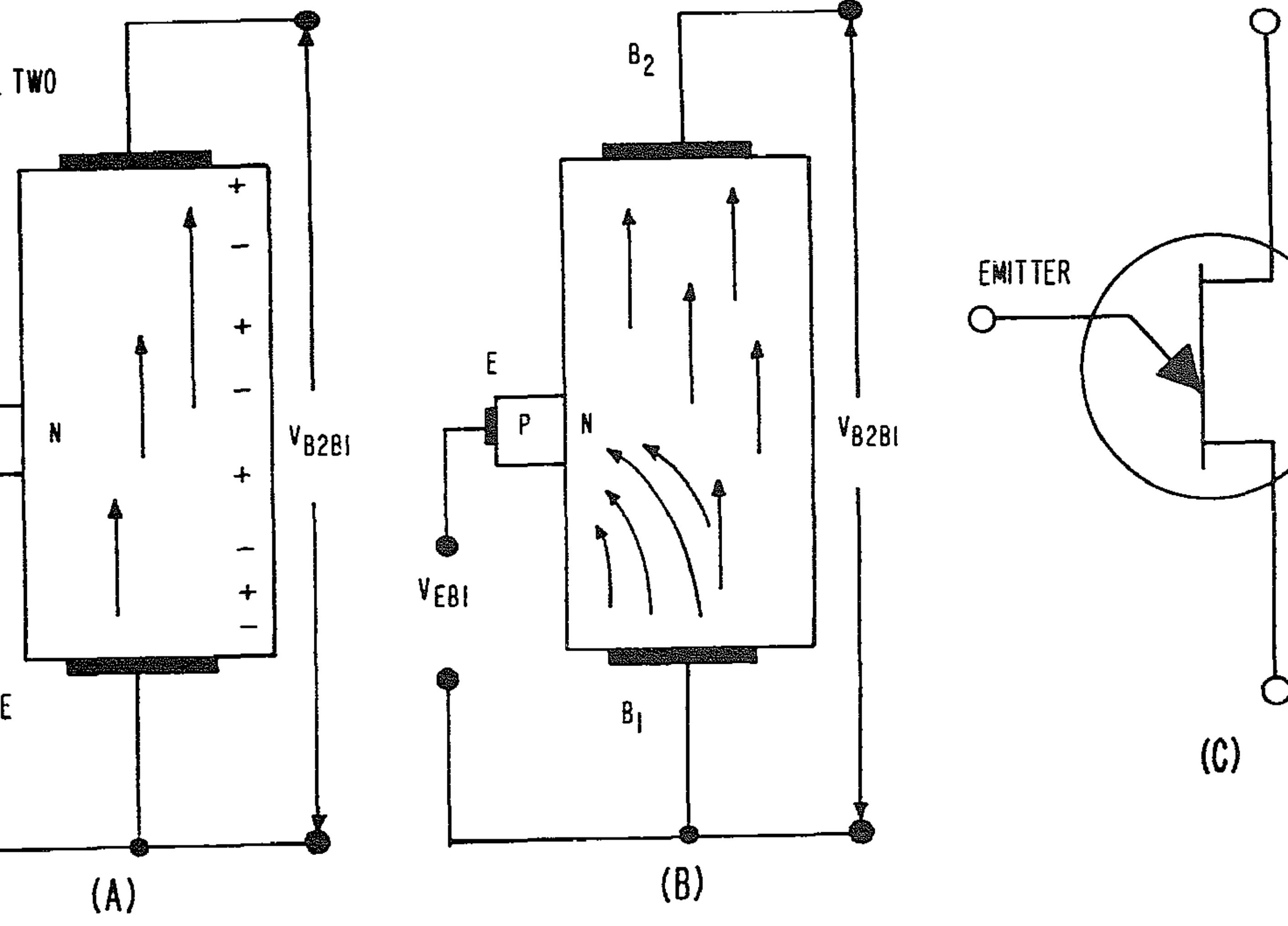


Figure 15--Silicon-Controlled Rectifier



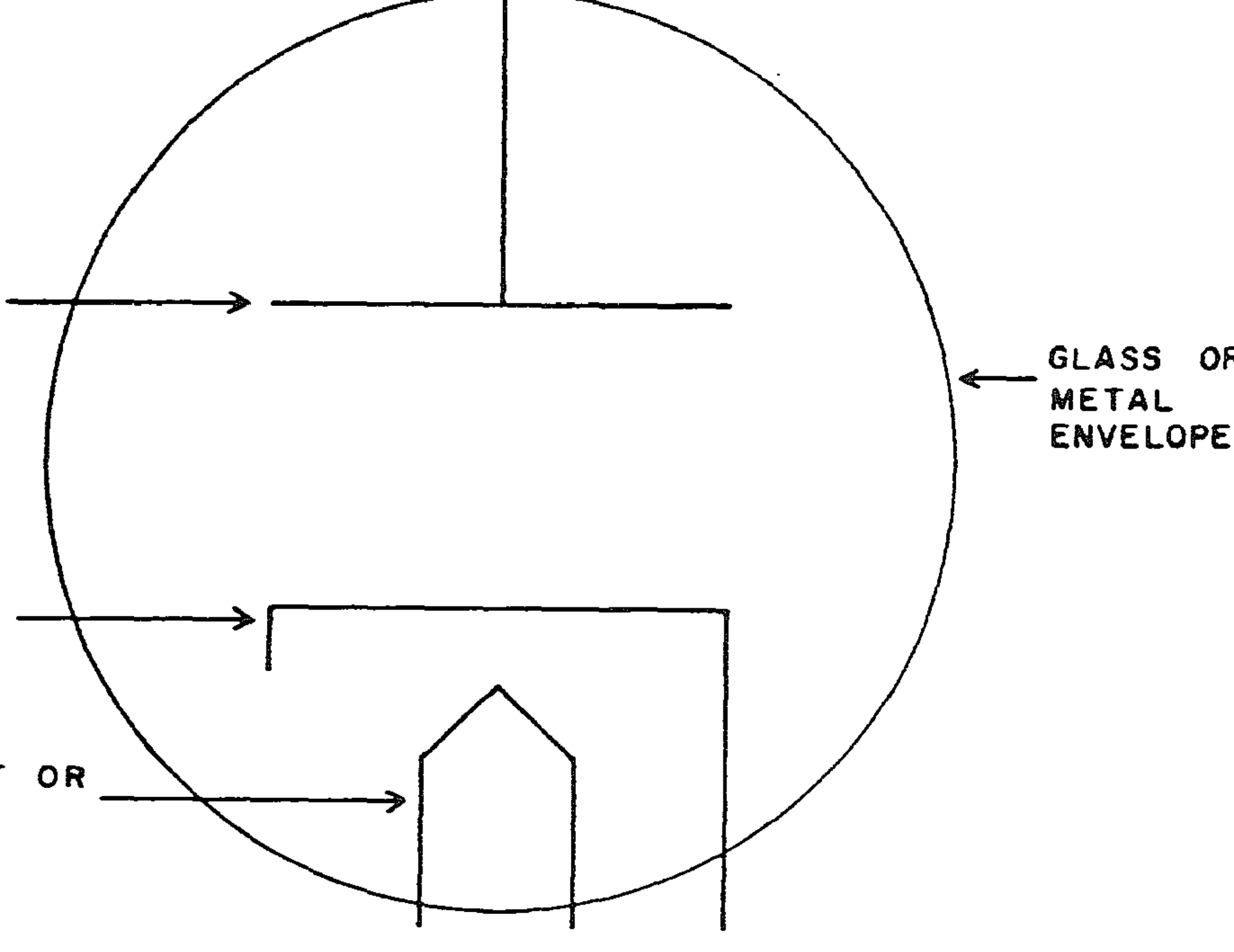
CATHODE
COMMERECIAL SYMBOL
V_{RB}
V_{RB}
I_{G3}
I_{G2}
V_{FB}
I_R
ANODE
GATE

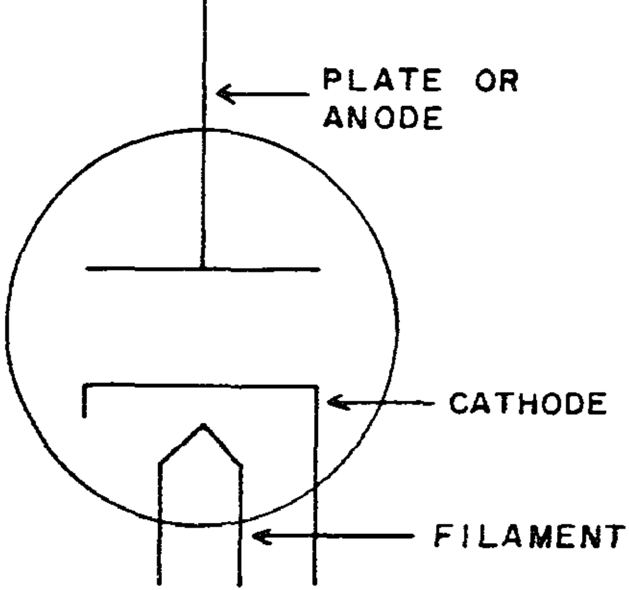

TWO
N
E
V_{B2B1}
B_2
E
P
N
V_{EB1}
B_1
EMITTER
(A)
(B)
(C)

c Circuit Analysis, Vol. I, NA 00-80-T-79, Chapter 4,
to 4-42.

TLINE

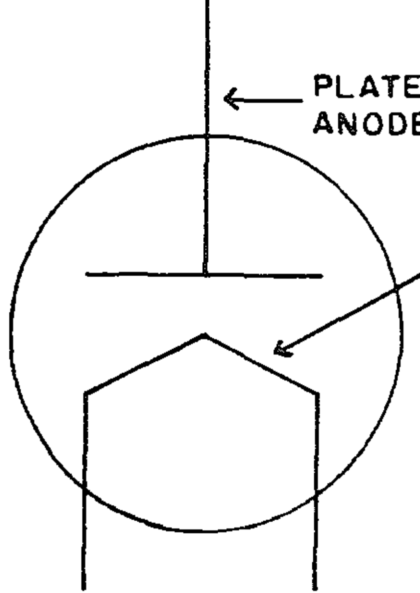
Construction of a Vacuum Tube.


OR
DE
IODE
MENT OR
TER
GLASS OR
METAL
ENVELOPE



INDIRECTLY HEATED CATHODE

Figure 3

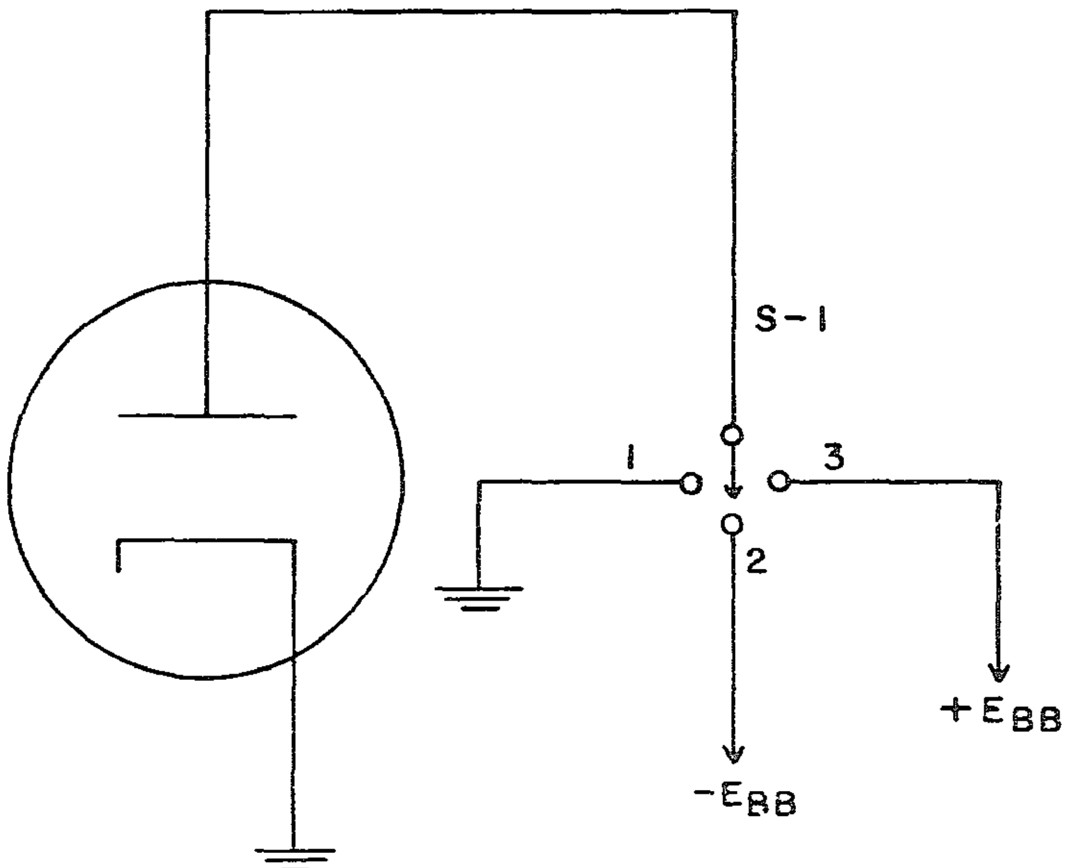


DIRECTLY HEATED CAT

Figure 2

B. Photoelectric emission

C. Cold cathode emission


S-1
1
2
3
-E_BB
+E_BB

uum Tube Circuit

ectronics, Vol. I, NAVPERS 10087-C, Chapter 7, pages

. Shrader, Electronic Communication, Chapter 9, Fourt
1980, McGraw-Hill Book Company Inc.

JTLINE

truction of a Triode Vacuum Tube

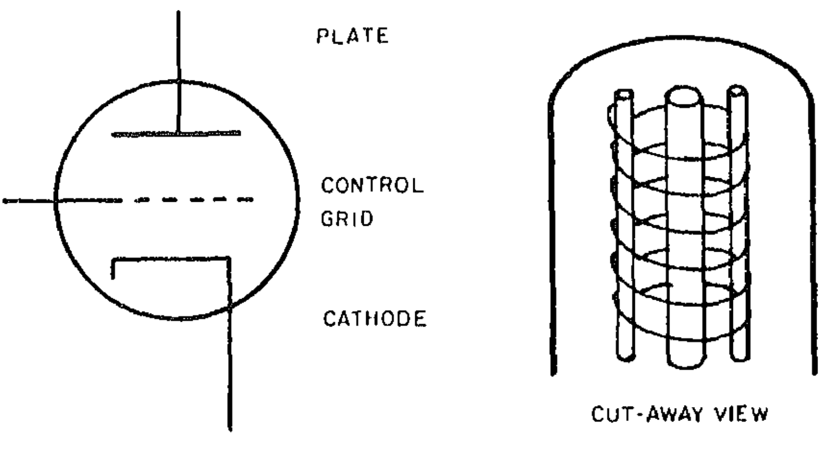
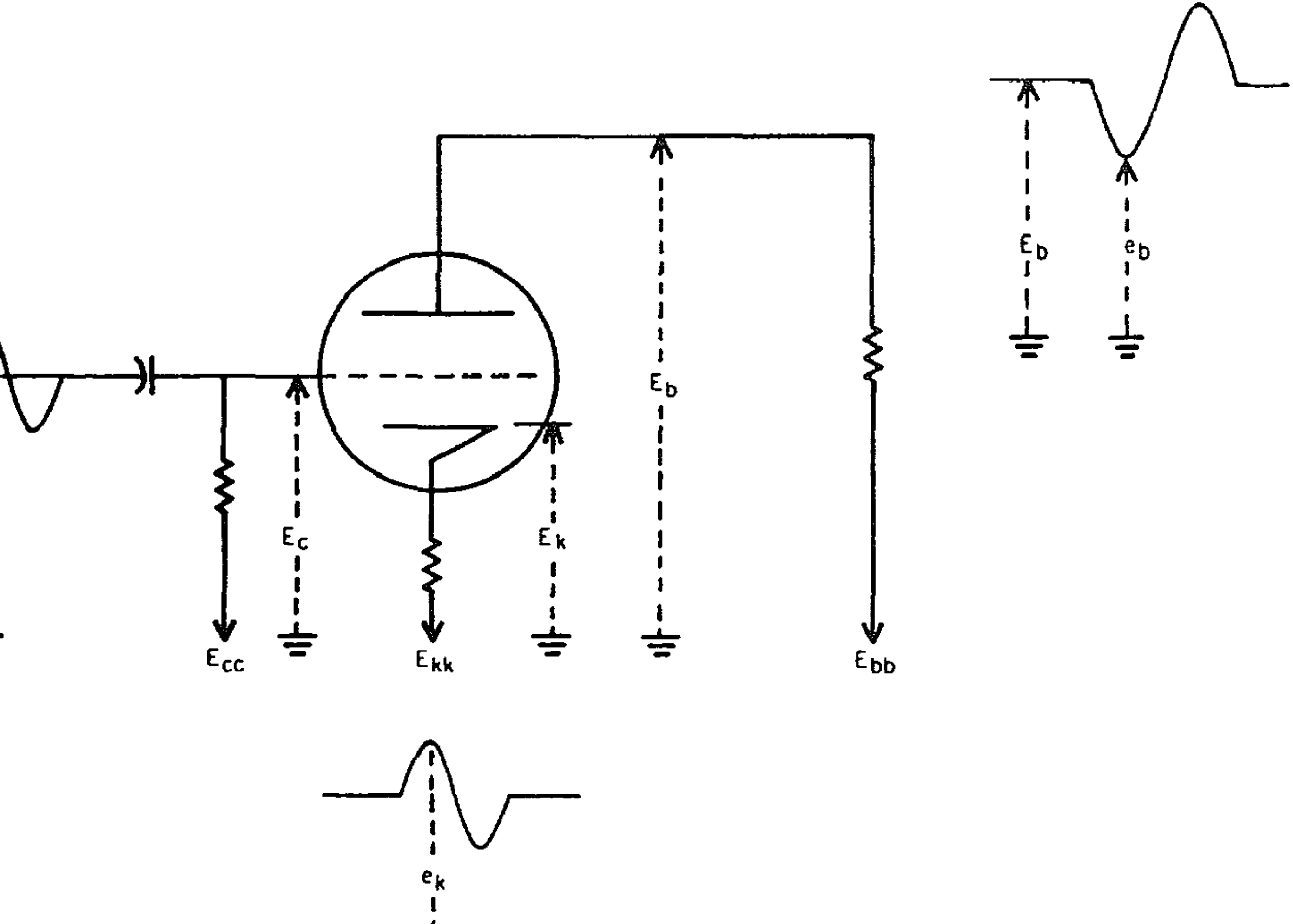


Figure 1 - Triode Vacuum Tube

II. Bias



E_b
e_b
E_b
E_c
E_k
E_{cc}
E_{kk}
E_{bb}
e_k

Tube Notations

IV. Vacuum Tube Static Characteristic Curves

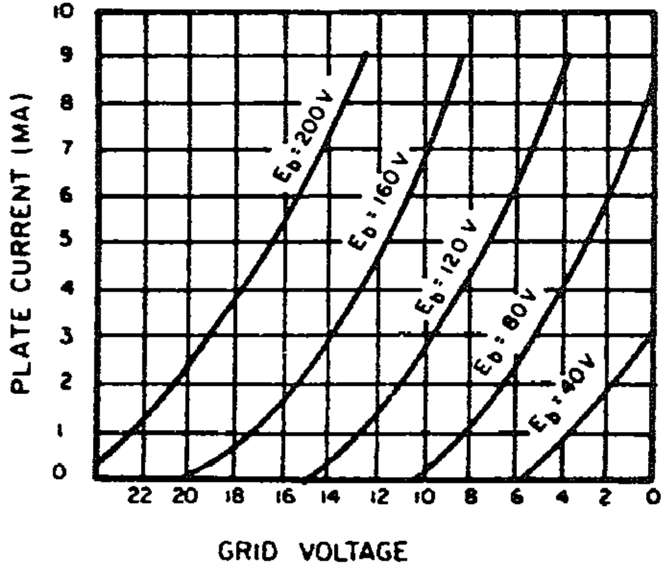


Figure 3 E_c-I_b GRID FAMILY OF CURVES

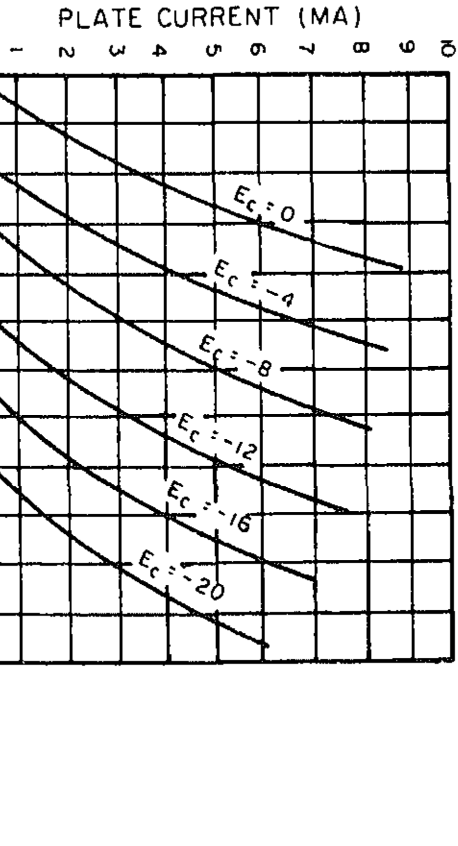
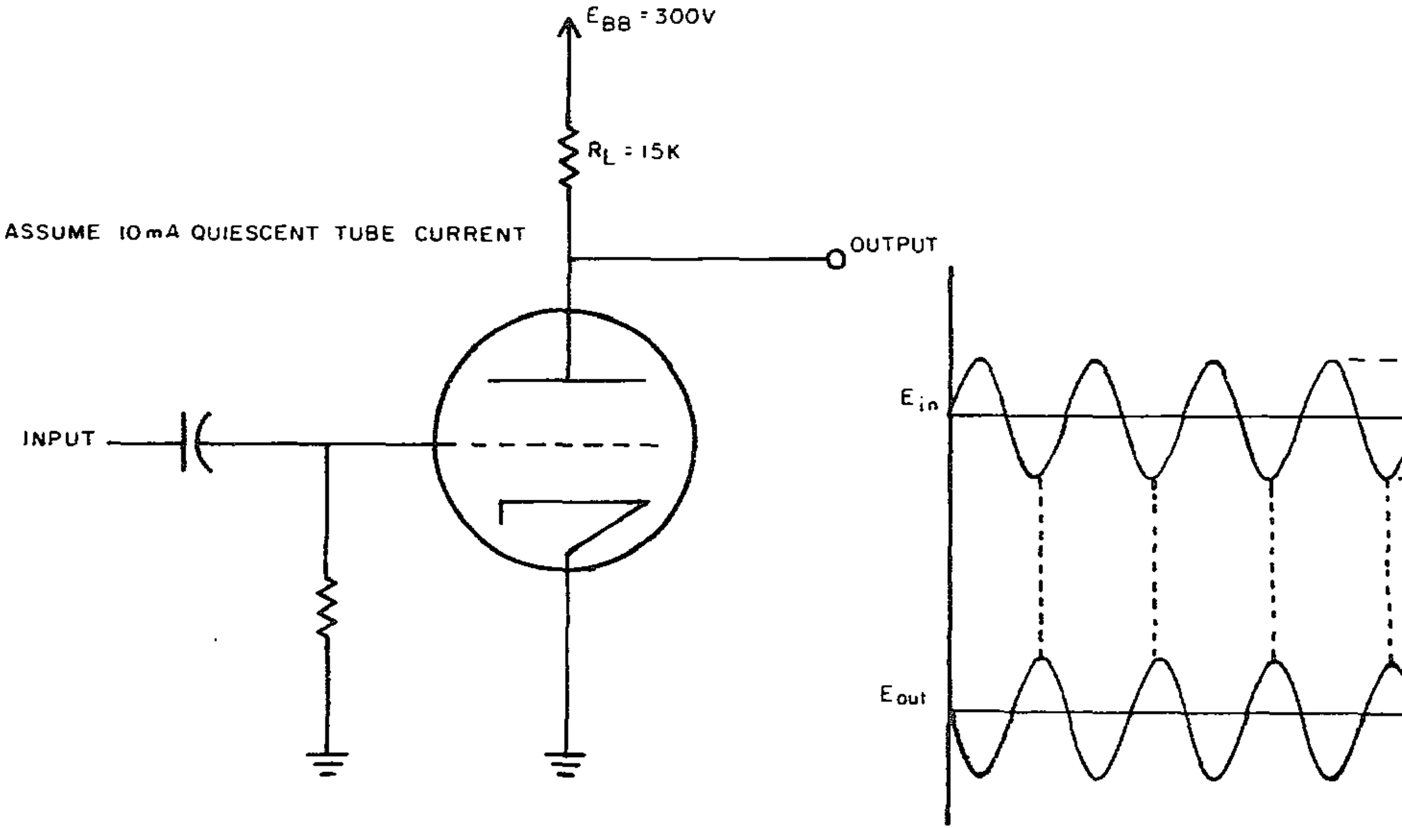


PLATE CURRENT (MA)
1 2 3 4 5 6 7 8 9 10
Ec = 0
Ec = -4
Ec = -8
Ec = -12
Ec = -16
Ec = -20

Characteristics of a Triode



ASSUME 10mA QUIESCENT TUBE CURRENT
E_{BB} = 300V
R_L = 15K
OUTPUT
INPUT
E_{in}
E_{out}

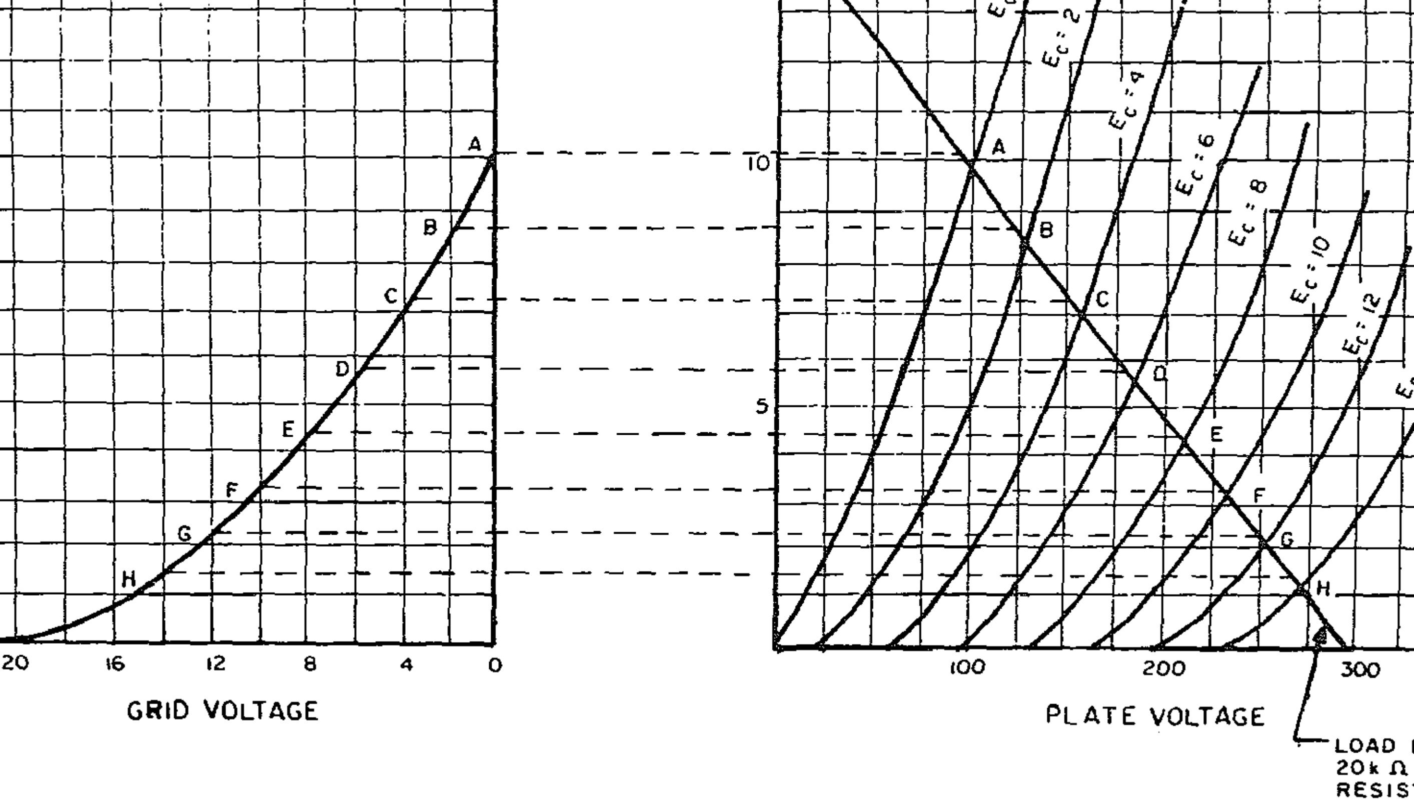
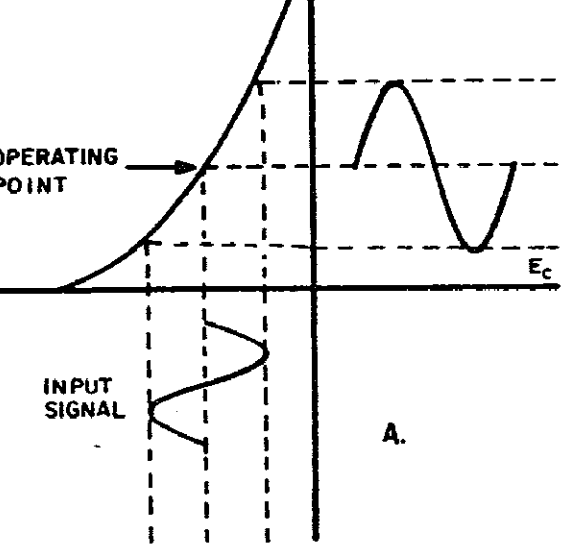


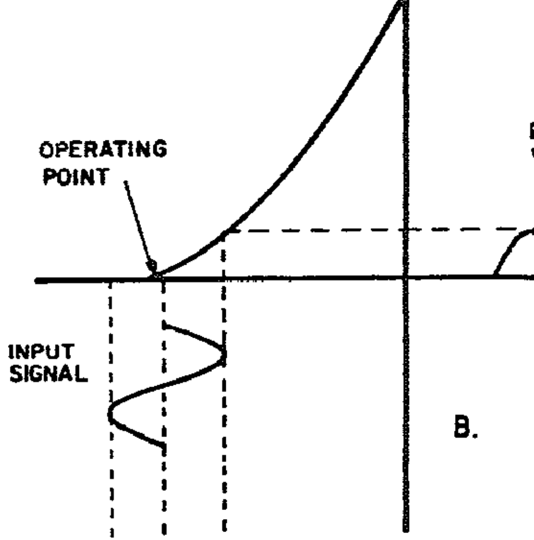
Figure 6 DYNAMIC TRANSFER CURVE (D.T.C.)

namic Transfer Curve (DTC)



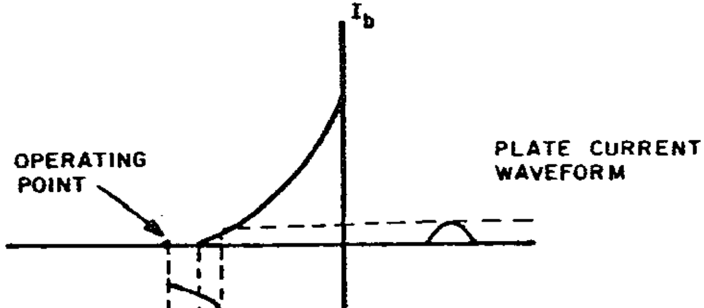
A.

CLASS A OPERATION



B.

CLASS B OPERATION



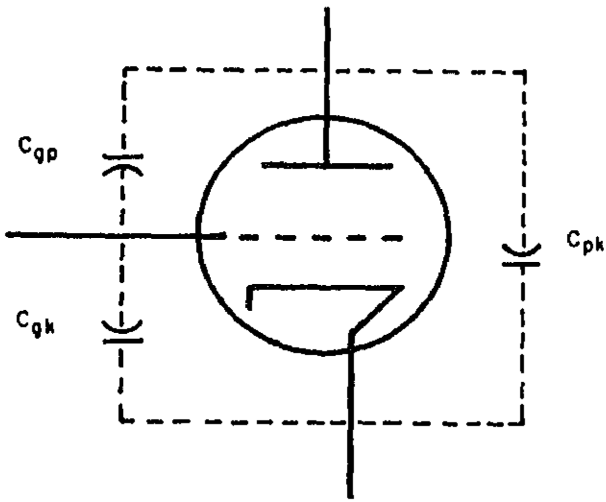


Figure 8 - Interelectrode Capacitance

Limitations of the Triode

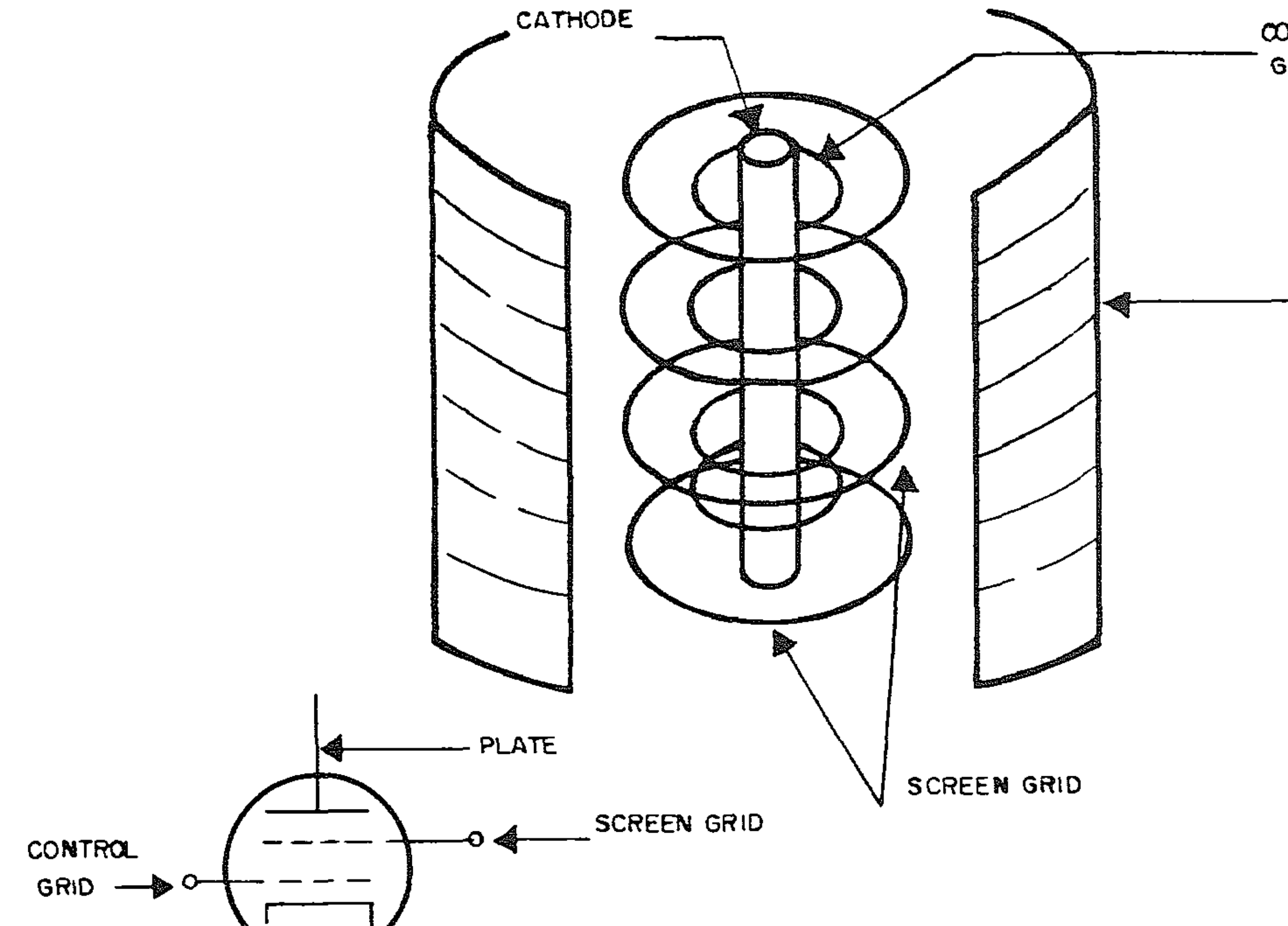
nic Circuit Analysis, Vol. I, NA 00-80-T-79, Chapter
-1 to 172.

ectronics, Vol. I, NAVPERS 10087-C, Chapter 7, pages

. Shrader, Electronic Communication, Chapter 9, Four
. 1980, McGraw-Hill Book Company Inc.

OUTLINE:

odes


CATHODE
PLATE
SCREEN GRID
SCREEN GRID
CONTROL
GRID

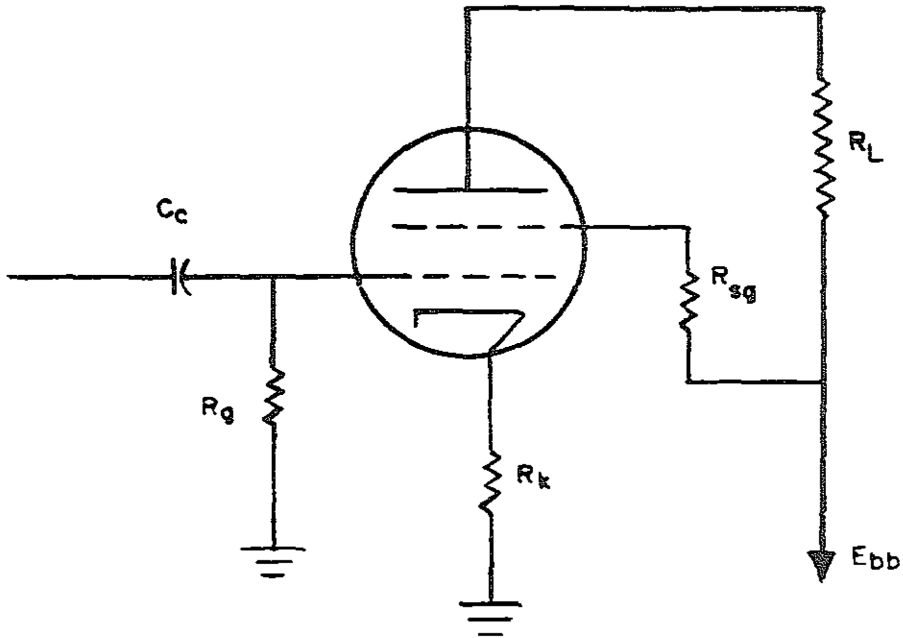


Figure 2 - TETRODE CIRCUIT

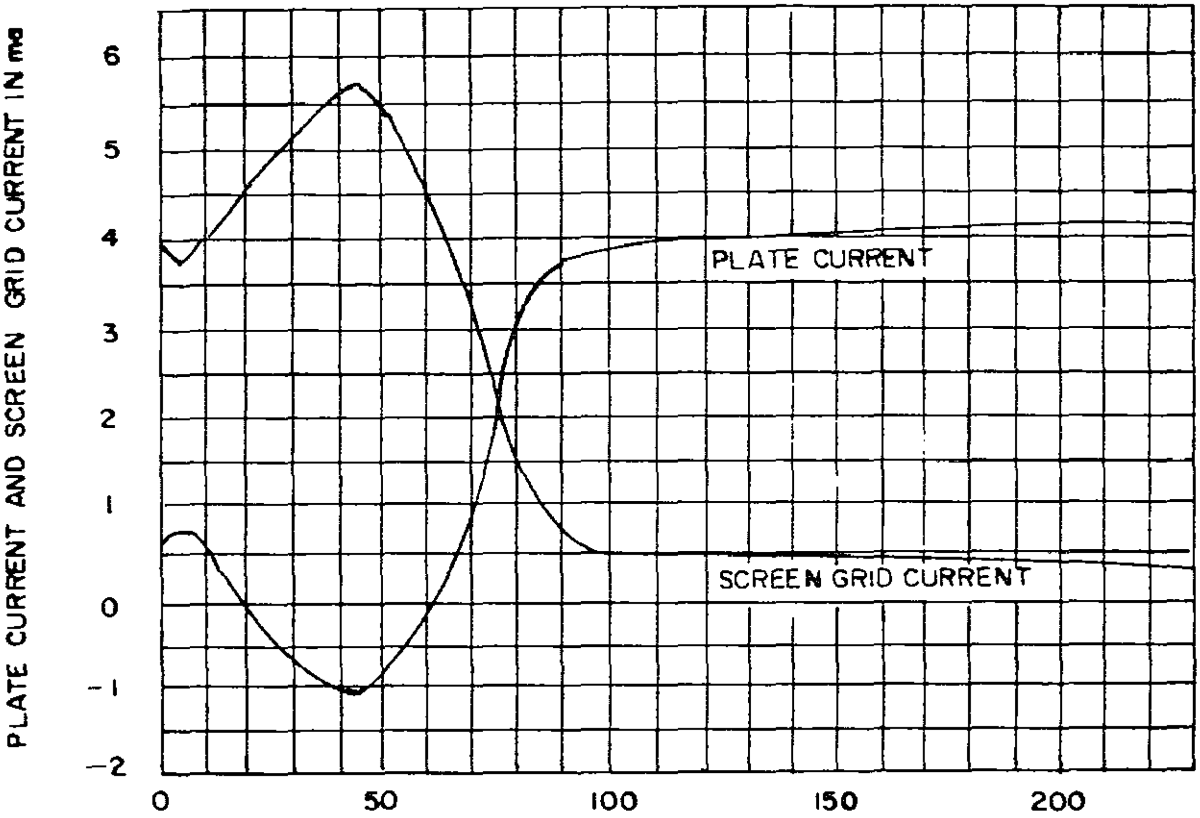


PLATE CURRENT AND SCREEN GRID CURRENT IN ma
6
5
4
3
2
1
0
-1
-2
0
50
100
150
200
PLATE CURRENT
SCREEN GRID CURRENT

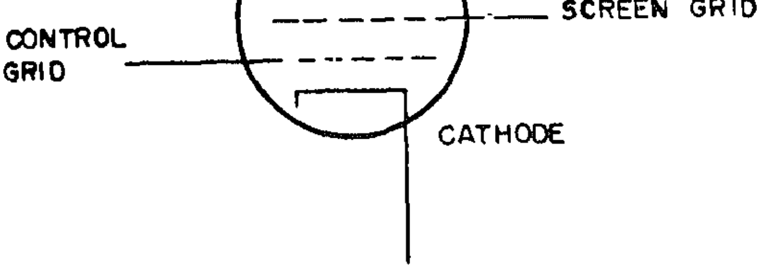


Figure 4 - PENTODE VACUUM TUBE

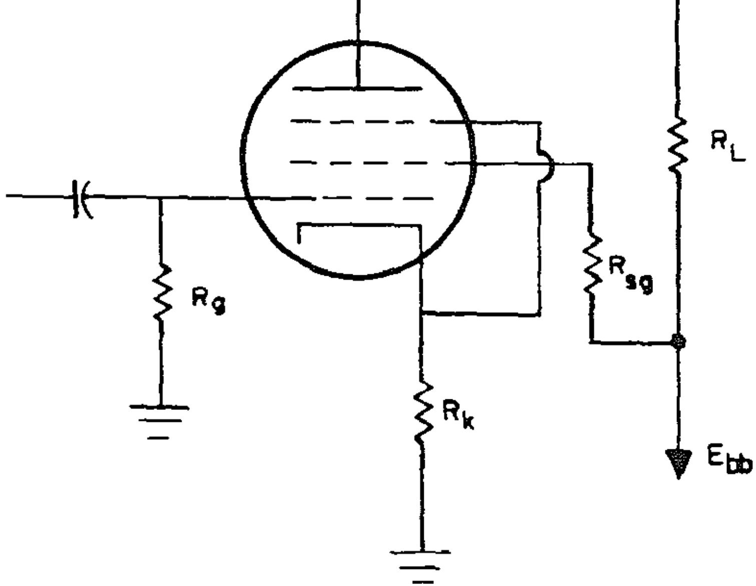


Figure 5 - PENTODE VACUUM TUBE CIRCUIT

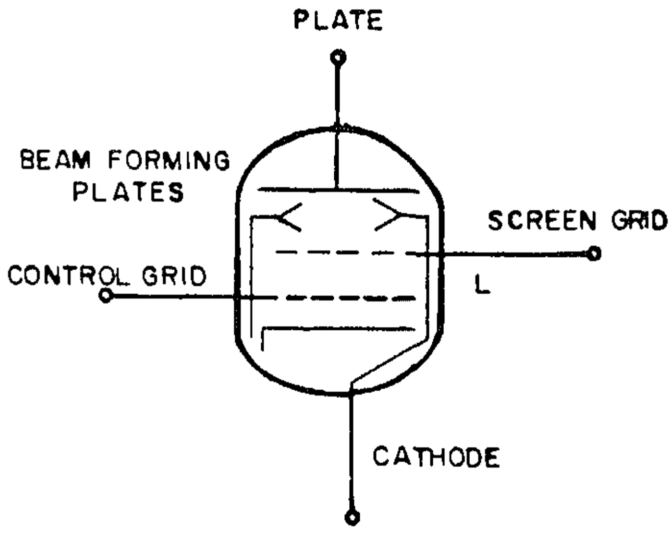


PLATE
BEAM FORMING
PLATES
SCREEN GRID
CONTROL GRID
L
CATHODE

ode-Ray Tubes

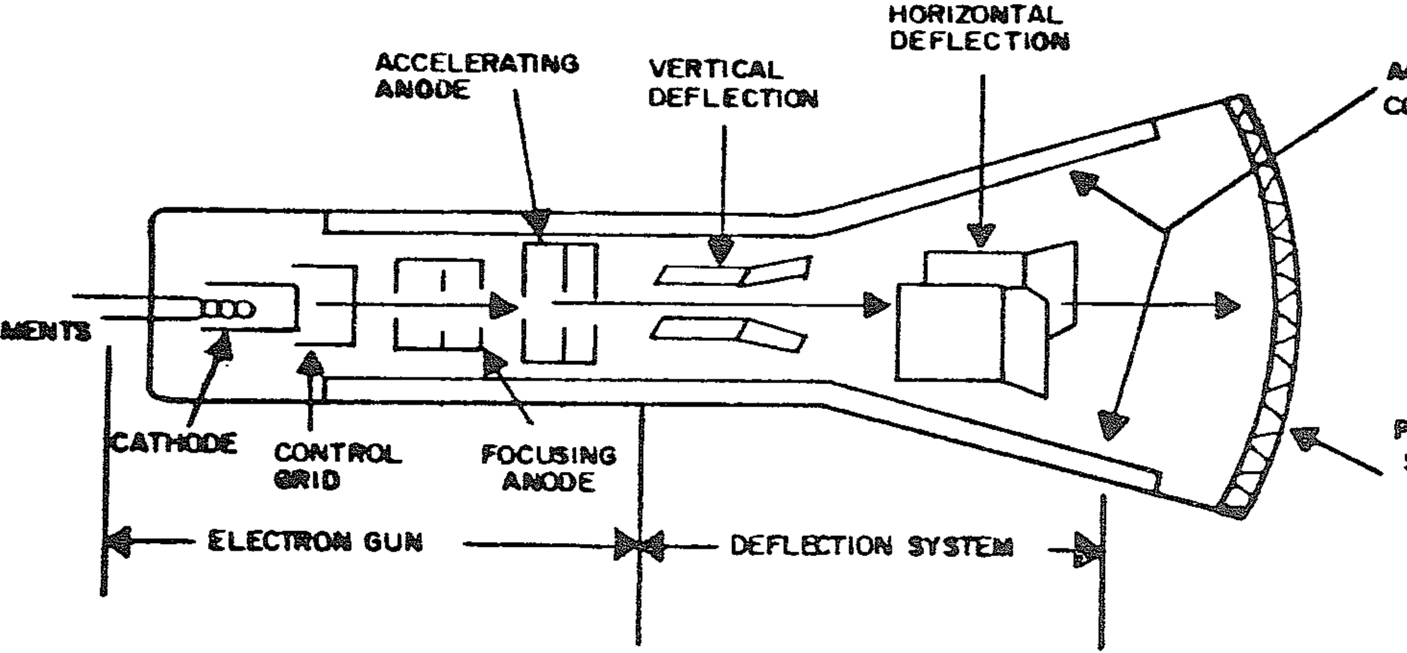


Figure 7- CATHODE RAY TUBE

$\frac{1}{2\pi fC}$

ly

R

r $E_{XC} = QE_A$

Only

$\frac{Z_1 Z_2}{Z_1 + Z_2}$

$\frac{E_A}{I_{line}}$

QX_L

Q^2R

$\left(\frac{X_L}{R}\right)^2$

$\frac{L}{RC}$

$= QI_{line}$

$P_a \cos\ \theta$

$\frac{P_t}{P_a} = \cos\ \theta$

d Parallel

$\frac{1}{2\pi\sqrt{LC}}$

Q

4. $BW = \frac{R}{2\pi L}$

5. $X_L = X_C = L/C$

6. $F_O = \frac{X_L}{2\pi L}$

Common Emitter Amplifier

1. $\beta = \frac{I_C}{I_B}$

2. $\beta = \frac{\alpha}{1 - \alpha}$

3. $I_{CEO} = I_{CBO}(\beta + 1)$

4. $I_C = (\beta)(I_B) + (I_{CBO})(\beta$ -

Common Base Amplifier

1. $= \frac{I_C}{I_E}$

2. $= \frac{\beta}{\beta+1}$

Common Collector Amplifier

1. $\gamma = \frac{I_E}{I_B}$

2. $\gamma = \beta + 1$

$$\mathrm{dB} = 10\log(10)\ P_1$$

$$\mathrm{dB} = 20\log(10)\ \frac{E_2}{E_1}\sqrt{\frac{Z_1}{Z_2}}$$

$$\mathrm{dB} = 20\log(10)\ \frac{I_2}{I_1}\sqrt{\frac{Z_2}{Z_1}}$$

dback Amplifiers

$$A_f = \frac{A_v}{1 - \beta A_v}$$

$$e_\varepsilon = e_{in} + \beta e'_{out} = e_{in} + e_f$$

$$e'_{out} = \frac{A_v e_{in}}{1 - \beta A_v} = e_{in}A_f = e_\varepsilon A_v$$

$$ed' = \frac{ed}{1 - \beta A_v}$$

$$\beta = \frac{R_i}{R_f + R_i} \qquad \frac{R_E}{R_C}$$

mps

$$E_{out} = \left(E_{in_2}\frac{R_f}{R_{s_2}}\right) + \left(-E_{in_1}\frac{R_f}{R_{s_1}}\right)$$

$$E_{out} = e_{in}\frac{R_f}{R_s}$$